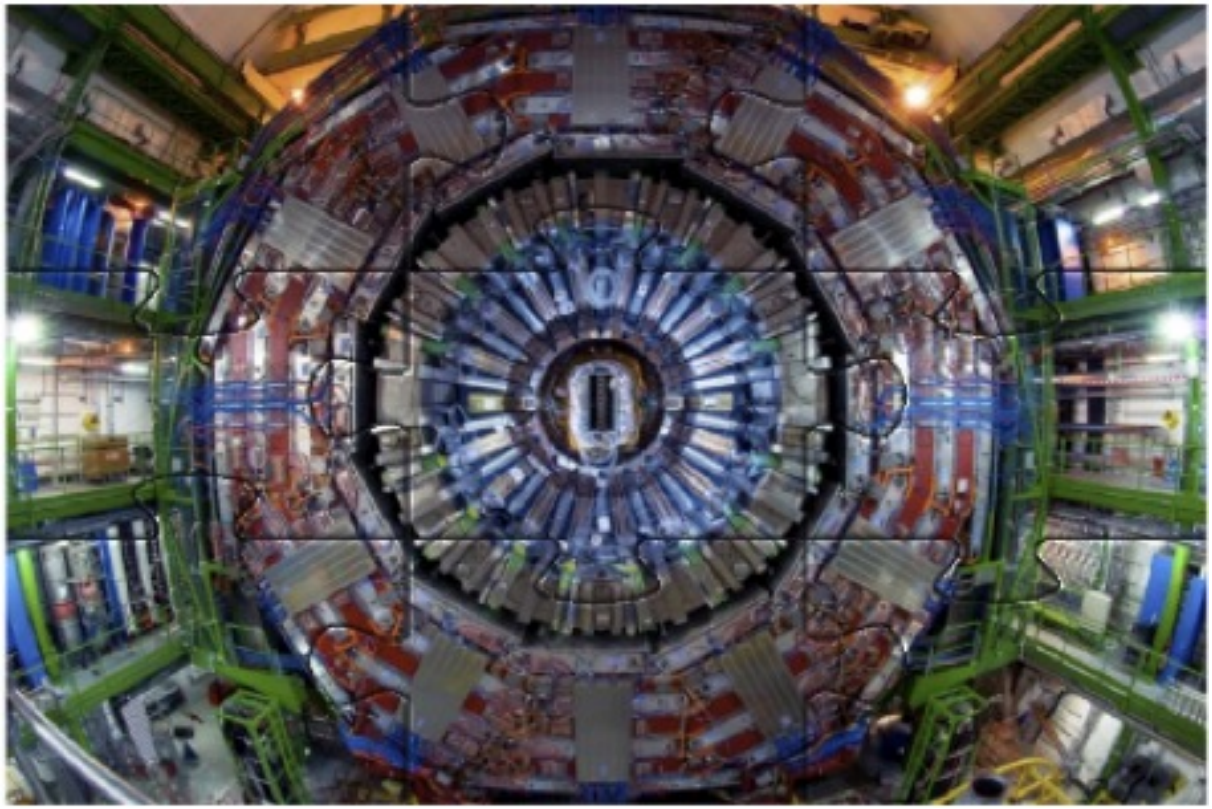
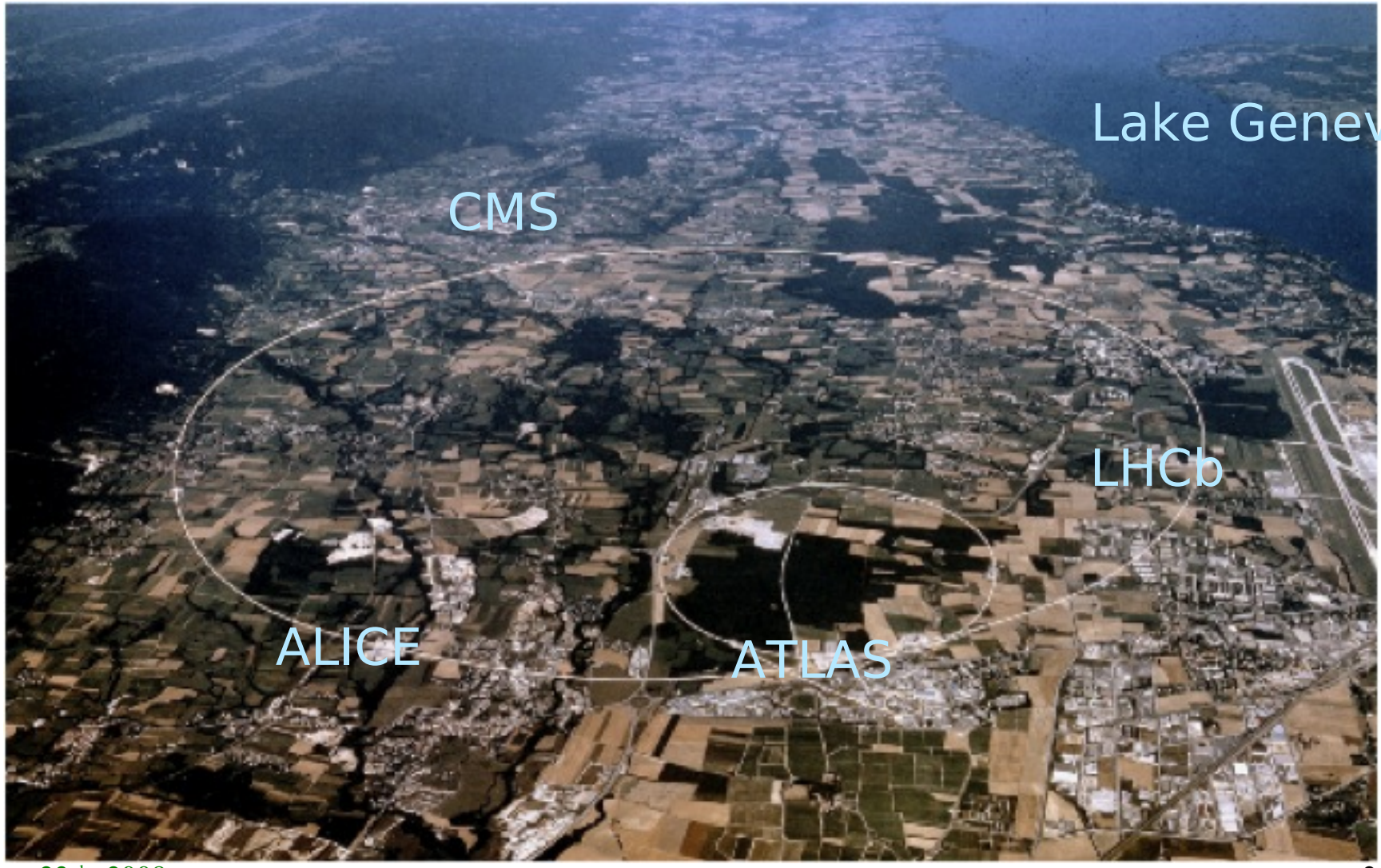
CMS Commissioning

How to compose a very very large jigsaw-puzzle

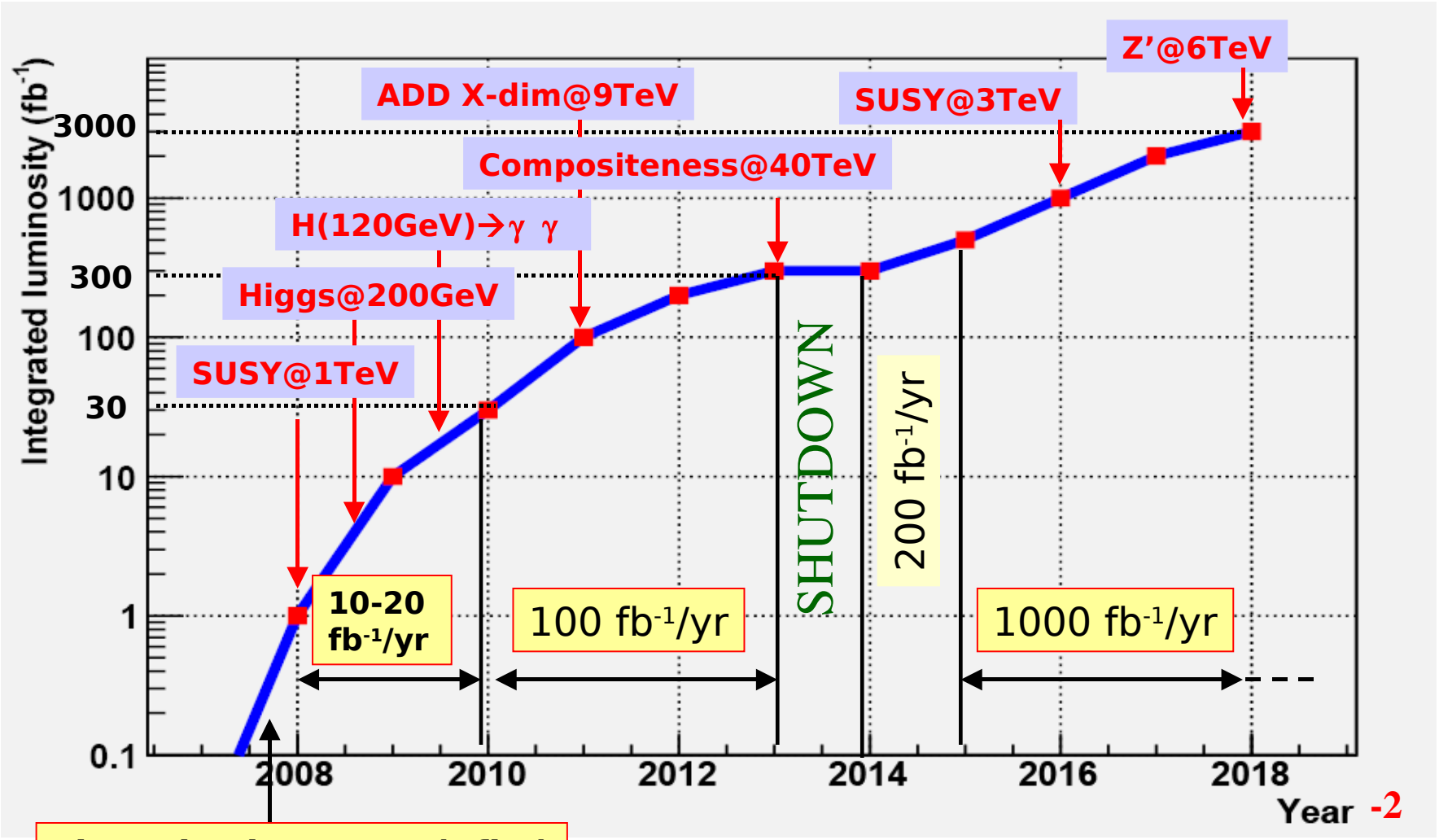
- LHC & CMS
- CMS construction
- Phases of commissioning
- Sept. 19th
- Cosmic runs and results
- Shutdown activities



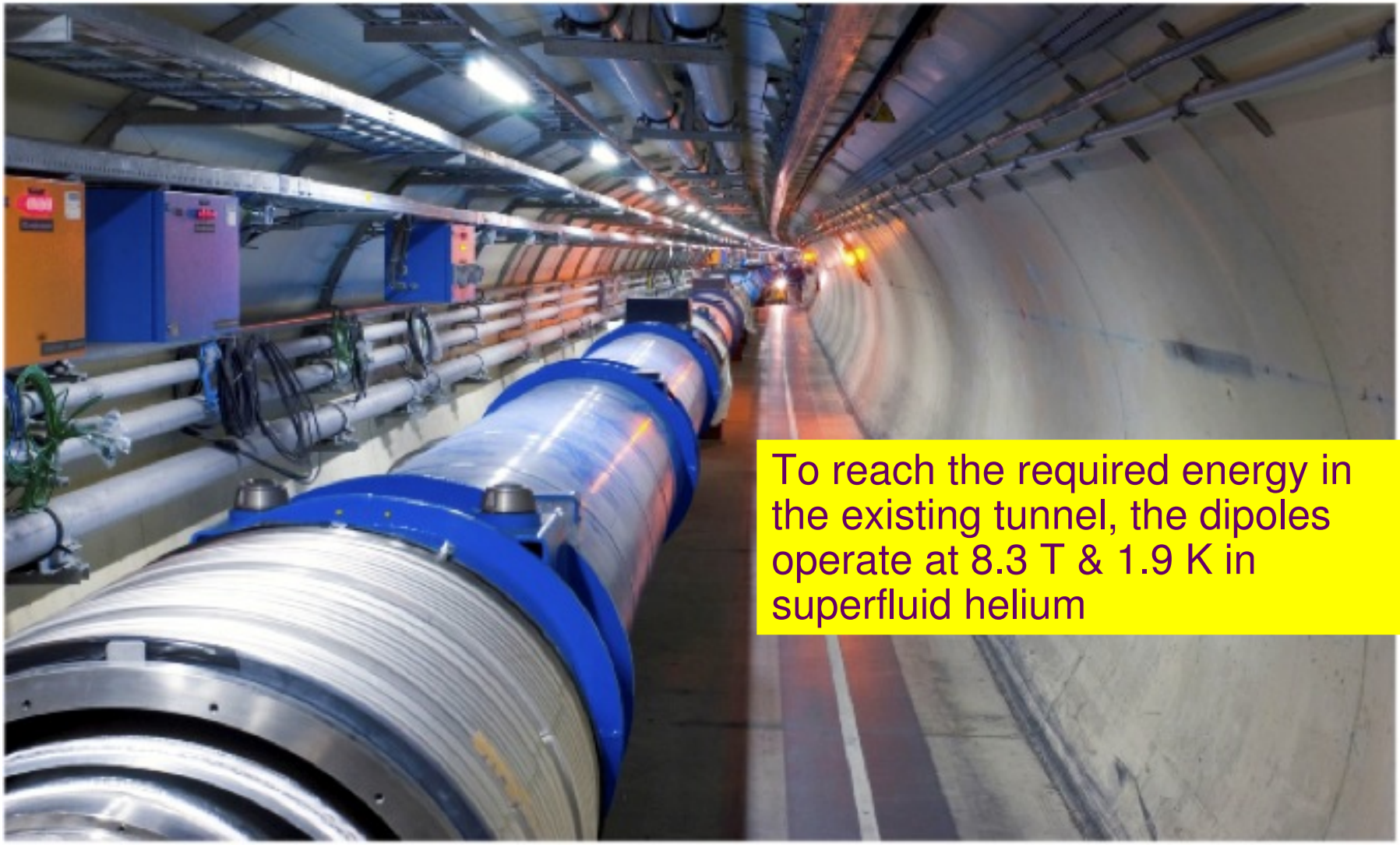
The CERN Site



LHC Luminosity Profile



LHC Accelerator - Dipoles



To reach the required energy in the existing tunnel, the dipoles operate at 8.3 T & 1.9 K in superfluid helium

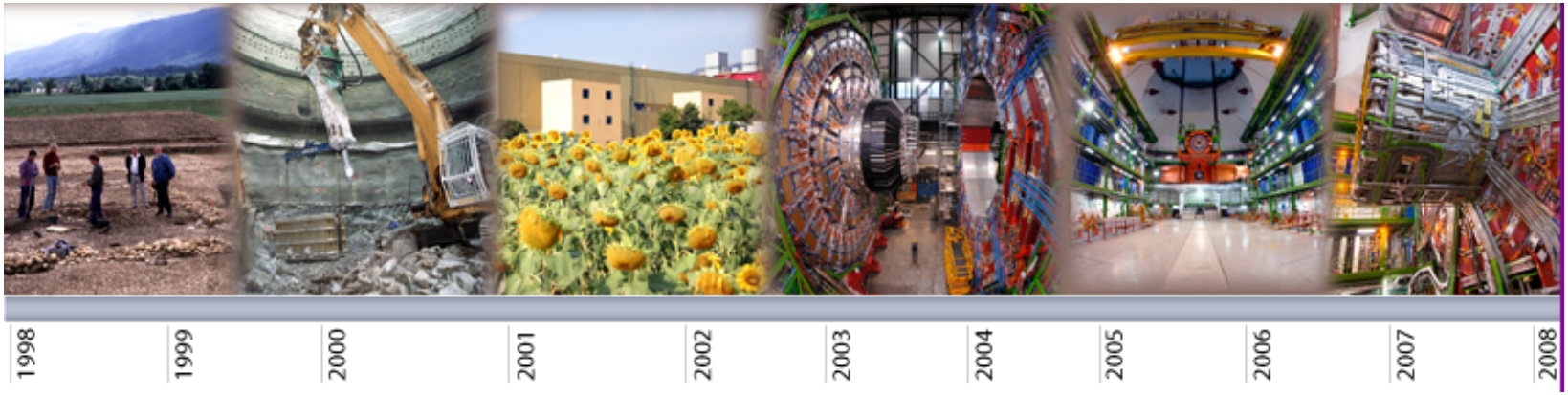
The Last Dipole Magnet, April 2007

30,000 km underground transport at a speed of 2 km/h!

The Interaction Points

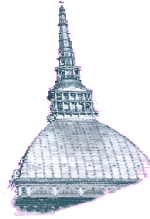
Special focusing quadrupole magnets ('Inner Triplets'), just before the interaction point. One of these broke last year.

History



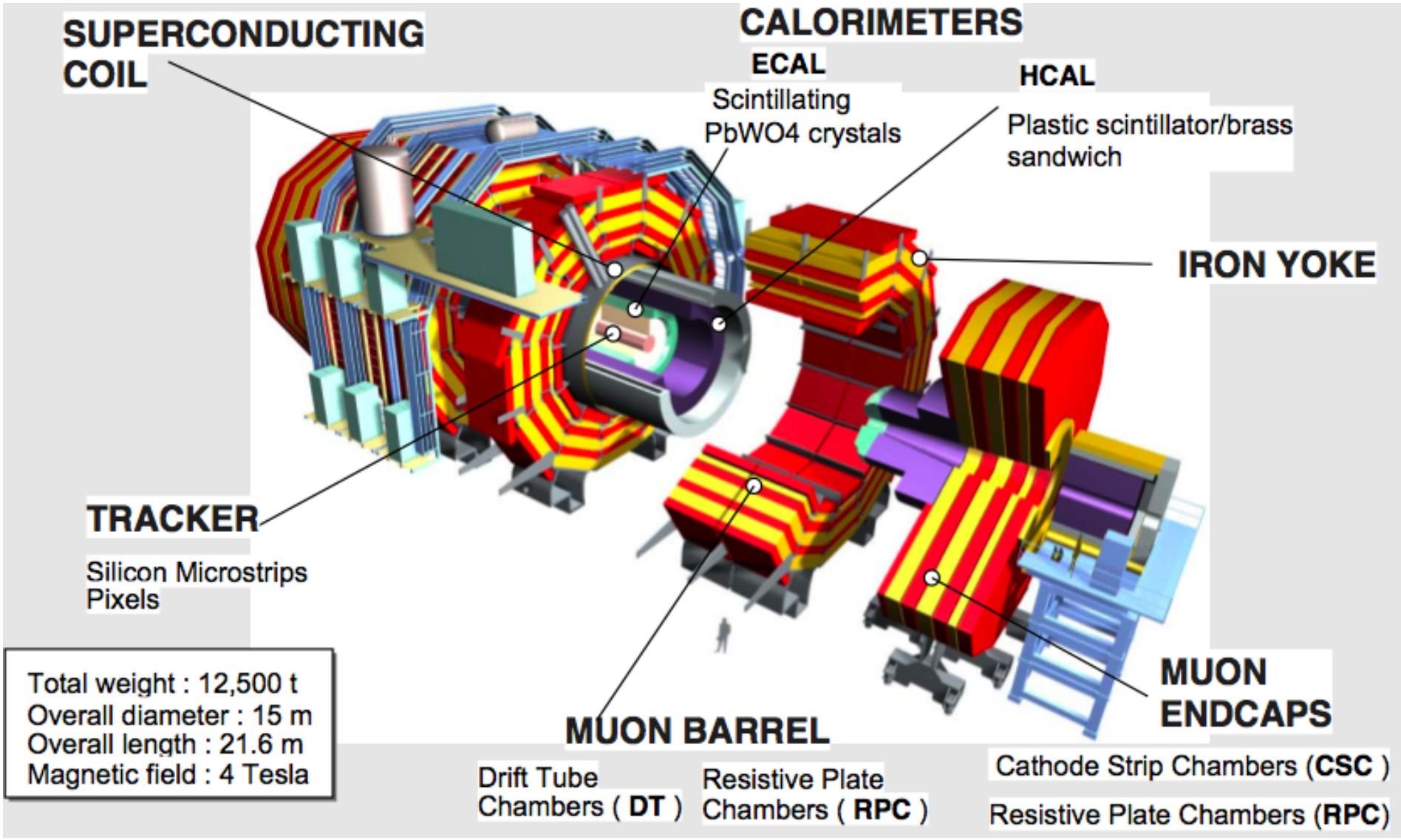
- Marc 1992: Evian conference
  - Ascot (air toroid, LAr calorimeter);
  - CMS (Compact solenoid, crystal calorimeter);
  - Eagle (toroid Fe, LAr calorimeter);
  - L3P (Large solenoid, crystal colorimeter).
- May 1992: Ascot ⊕ Eagle = ATLAS (air toroid, LAr calorimeter);
- October 1992 : Letter of intent: ATLAS; CMS; L3P.
- April 1993: LHC committee supports ATLAS, CMS.
- September 1994: CMS choose $PBWO_4$ (instead of cesium fluoride)
- CMS approved: January 1996

CMS design (Evian 1992):



- Redundant and robust μ trigger and ID
- Best e/γ calorimeter consistent with 1)
- Efficient tracking consistent with 1) and 2)
- Hermetic calorimeter
- Affordable

CMS reality

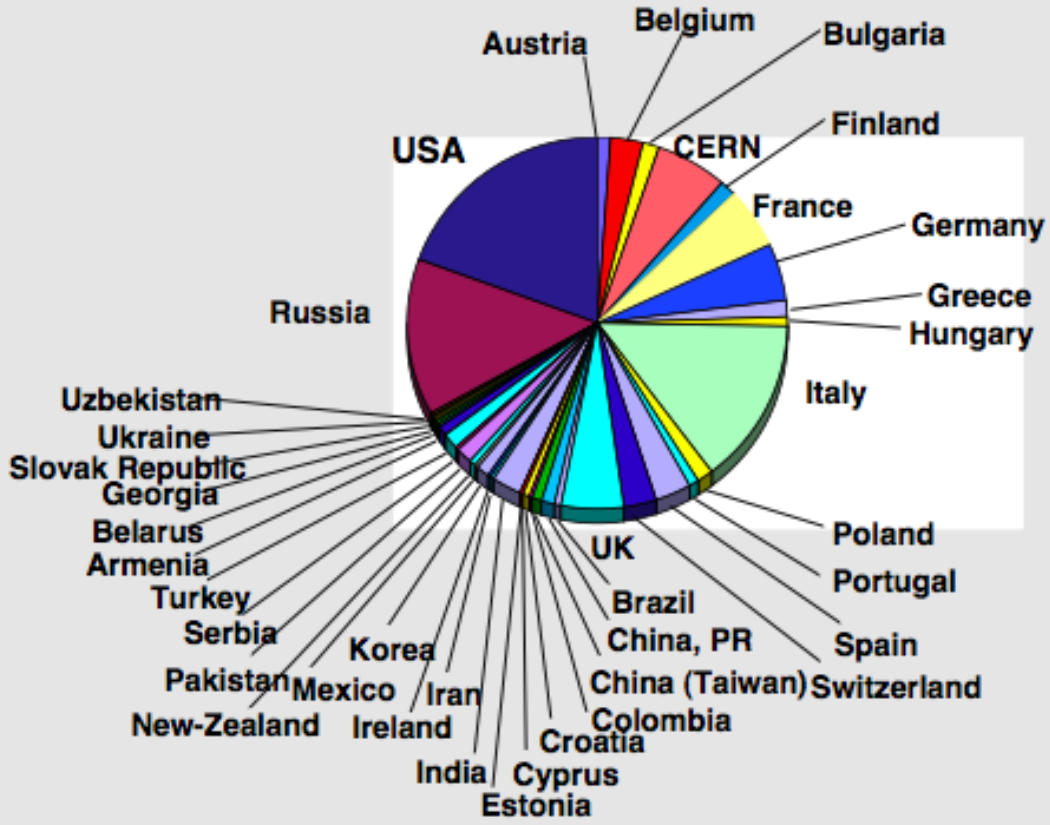

SUPERCONDUCTING COIL
CALORIMETERS
ECAL
Scintillating PbWO4 crystals
HCAL
Plastic scintillator/brass sandwich
IRON YOKE
TRACKER
Silicon Microstrips
Pixels
Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla
MUON BARREL
Drift Tube Chambers (DT)
Resistive Plate Chambers (RPC)
MUON ENDCAPS
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)

Who is who….

	Institutions
Member States	61
Non-Mem. States	64
USA	49
Total	174

	Scientists
Member States	1055
Non-Mem. States	428
USA	547
Total	2030

Associated Institutes	
Number of Scientists	46
Number of Laboratories	8



Joe Incandela, HCP 2006, Duke University, May 22! 2006

May, 04 2006/gm

2030 Scientific Authors, 38 Countries, 174 Institutions

The CMS magnet

CMS is built around a huge magnet:

Nominal field: 4 T

Magnetic length: 12.5 m

Cold bore diameter: 6.3 m

Nominal current: 19.14 kA

Stored energy: 2.6 GJ

Radiation thickness of cold mass: 3.9 X_0

Which requires a huge return yoke:

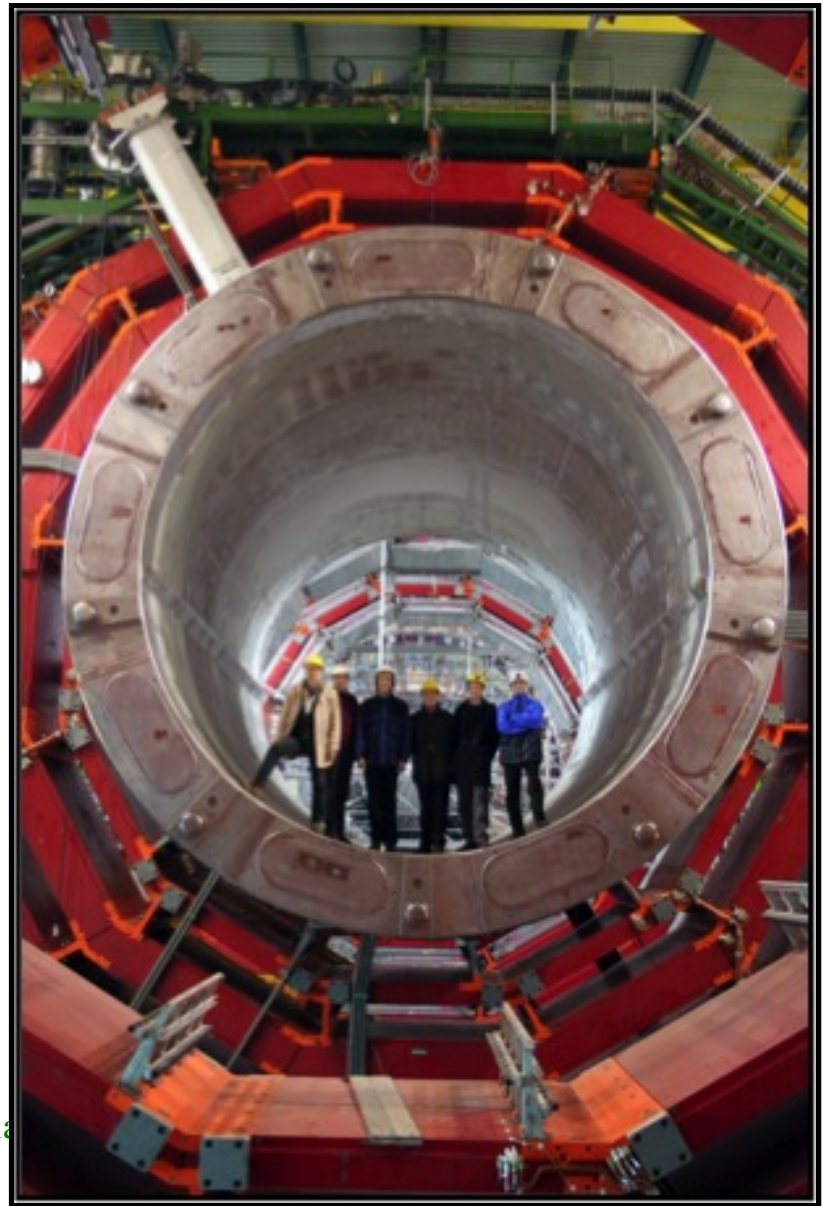
Thickness of the iron layers in barrel 300, 630 and 630 mm

Mass of iron in barrel 6000 t

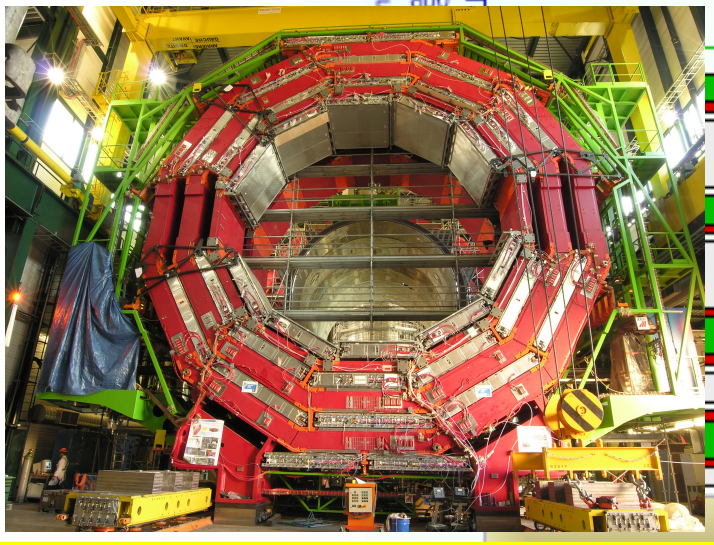
Thickness of iron disks in endcaps 250, 600 and 600 mm

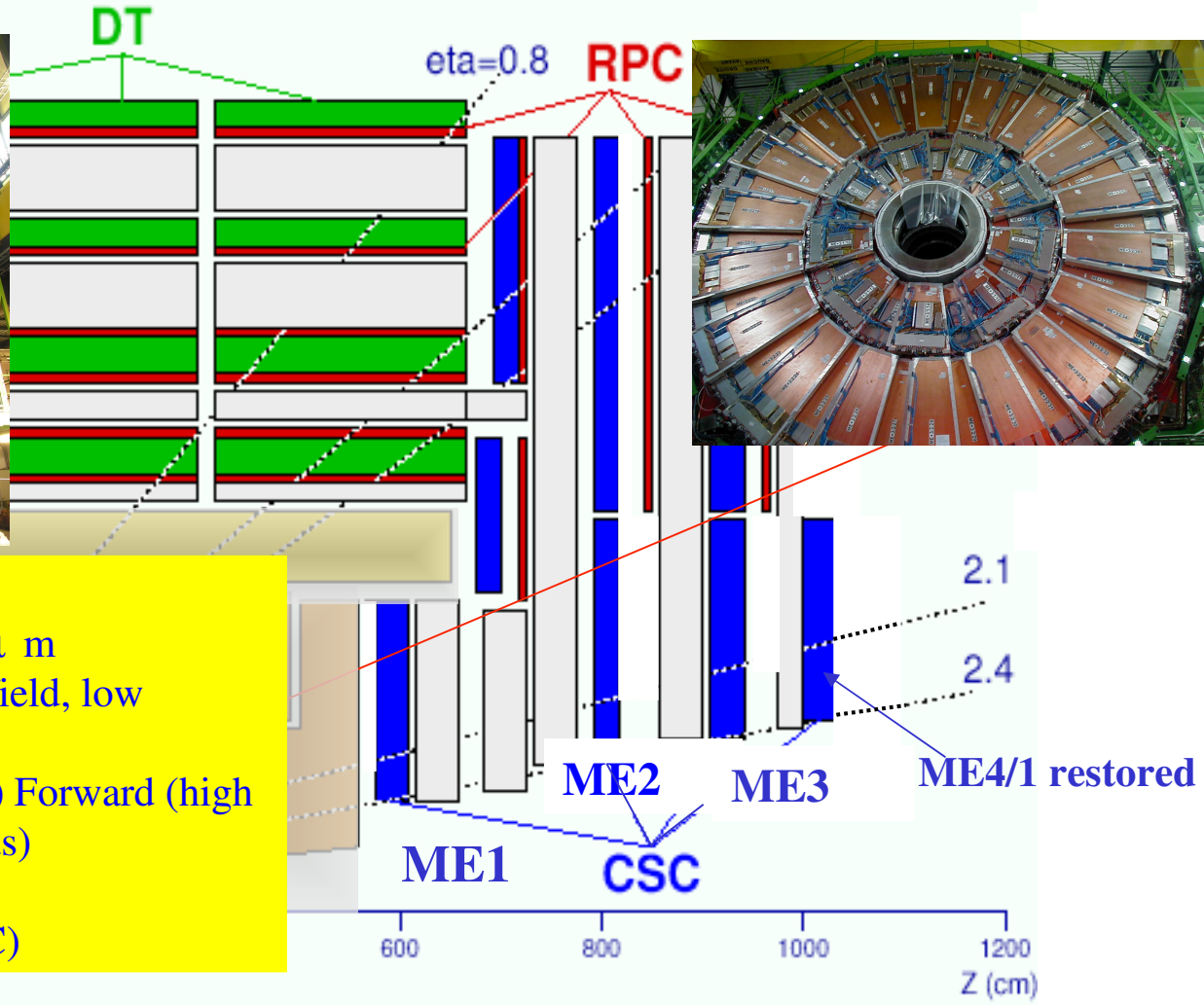
Mass of iron in each endcap 2000 t

Total mass of iron in return yoke 10 000 t



Muon System





Technology

- Good position resolution ~150-200 μ m
  - Drift Tubes (DT) central (low field, low radiation and background)
  - Cathode Strip Chambers (CSC) Forward (high field, radiation and backgrounds)
- Speed for triggering and redundancy
  - Resistive Plate Chambers (RPC)

Hadron calorimeters

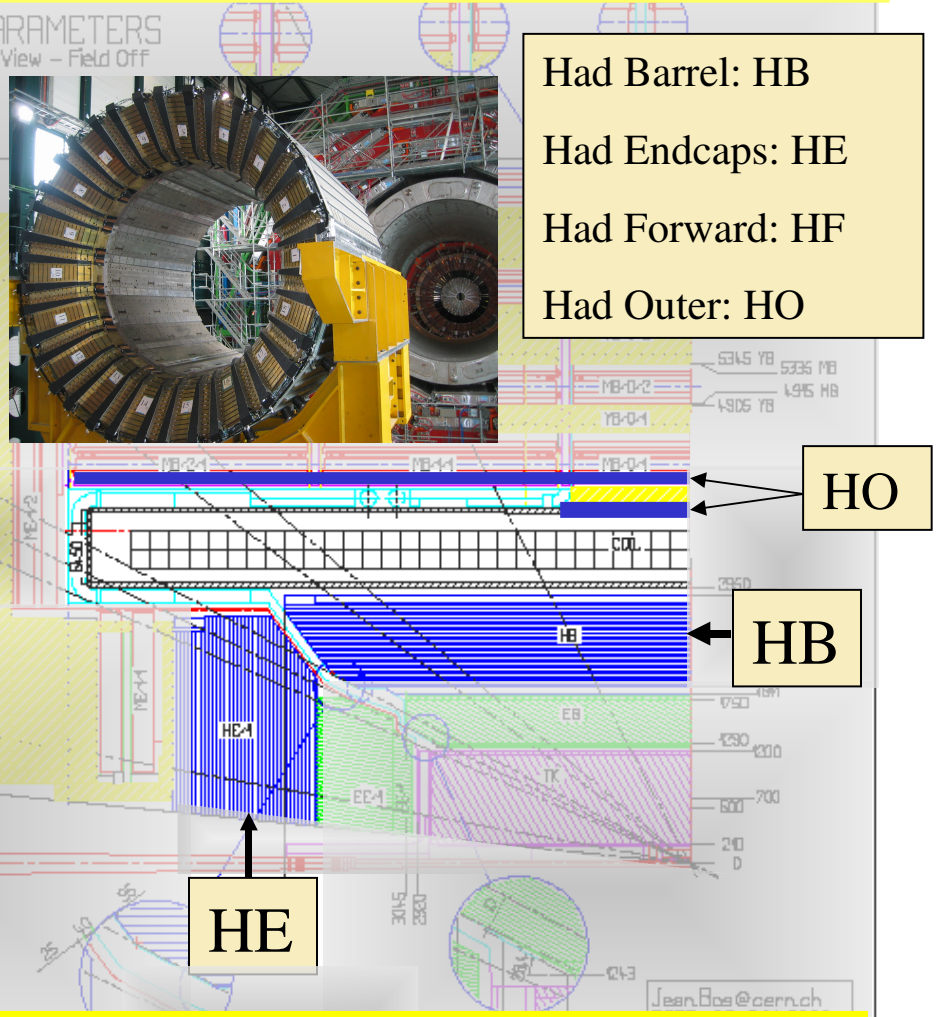
HB: $|\eta|<1.3$;
- 5.8 λ @ $\eta = 0$ (+ 1.1 λ for E B)
- 10.6 λ @ $\eta = 1.3$ (+ 1.1 λ for E B)
- One longitudinal segmentation

HO uses solenoid and 19.3 cm steel plate to extend HB to at least 11 λ

HE: $1.3<|\eta|<3$;
- ~ 10 λ including EE
- 2 (or 3) longitudinal segmentations

HF: $3<|\eta|<5$
- ~ 10 λ

Granularity: $\Delta\phi \times \Delta\eta = 0.087 \times 0.087$ for $|\eta|$ <



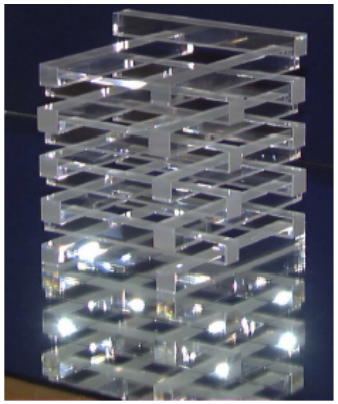
HB & HF: Brass Absorber and Scintillating tiles.

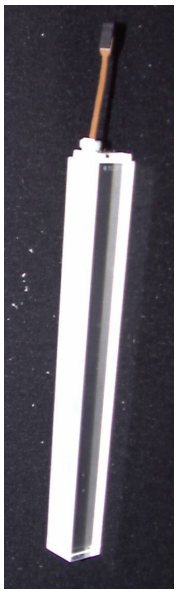
HO: Scintillator "catcher". HF: Iron and Quartz fibers

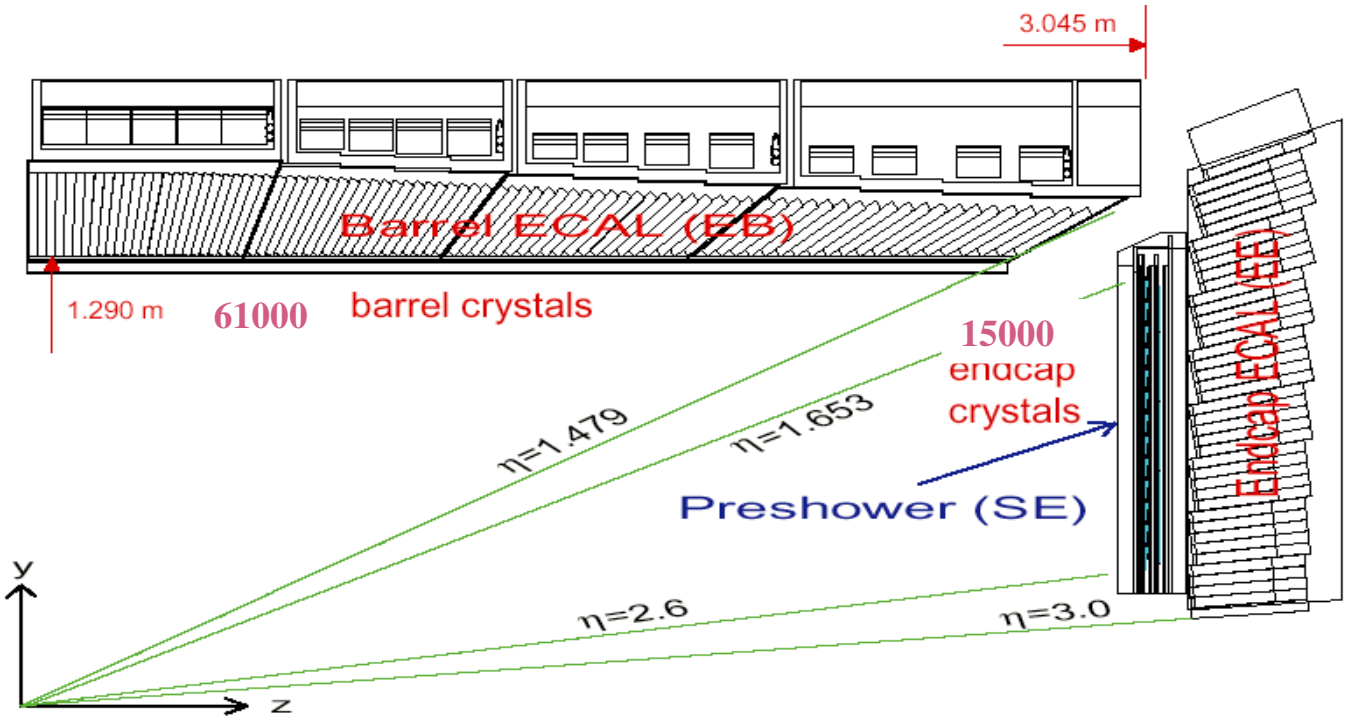
Electromagnetic calorimeter

Material	$PbWO_4$	Pb	Fe
Density (g/cm^3)	8.3	11.3	7.9
X_0 (mm)	8.9	5.6	17.6

$R_{Moliere}$ 2.2 cm
Radiation Resistance:
10^5 Gy (10 Mrad)



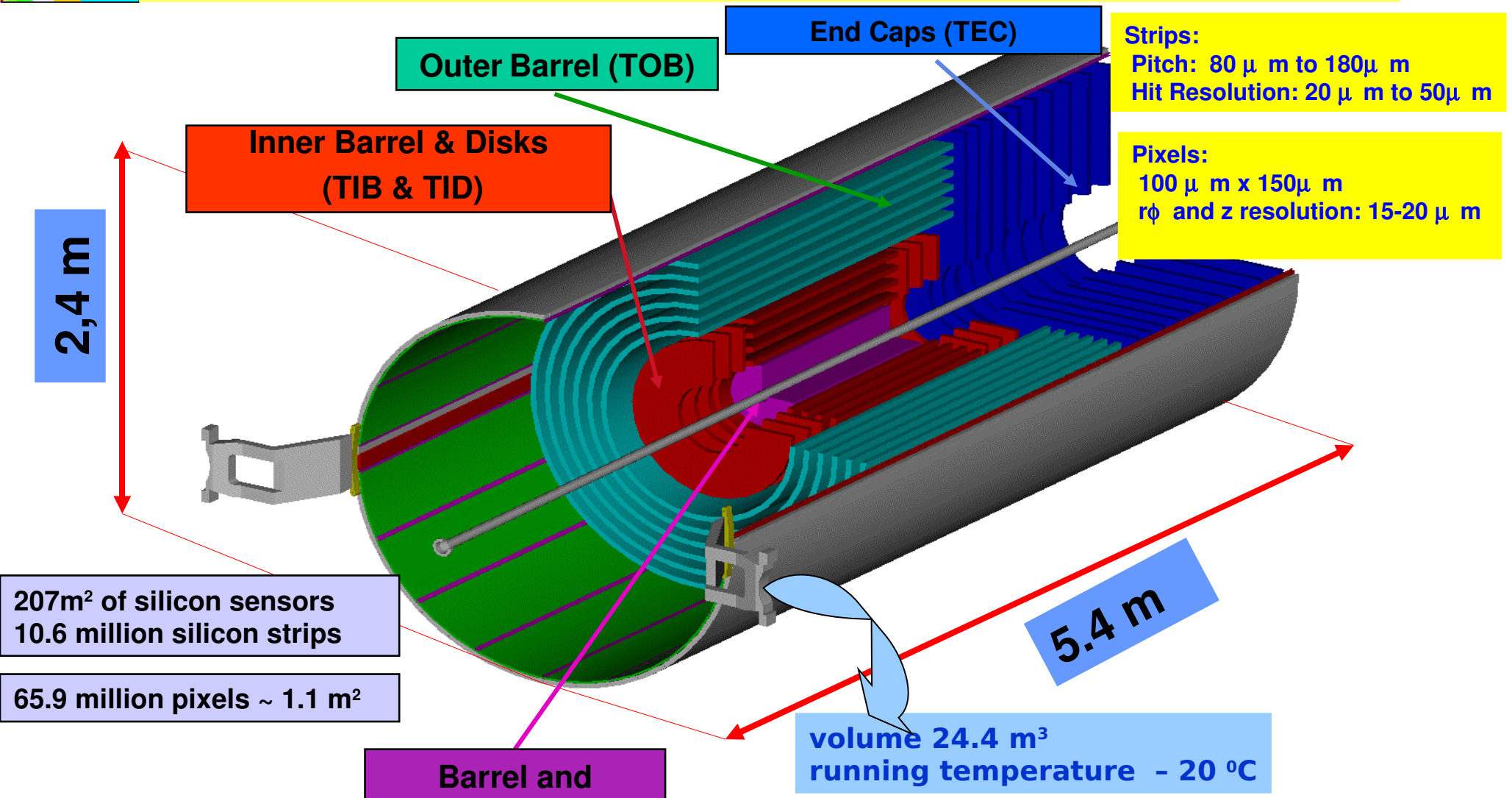




Barrel: 2.4x2.4x23 cm^3, ~ 25 λ

Endcap: 3x3x22 cm^3 ~ 24 λ

All Silicon Tracker



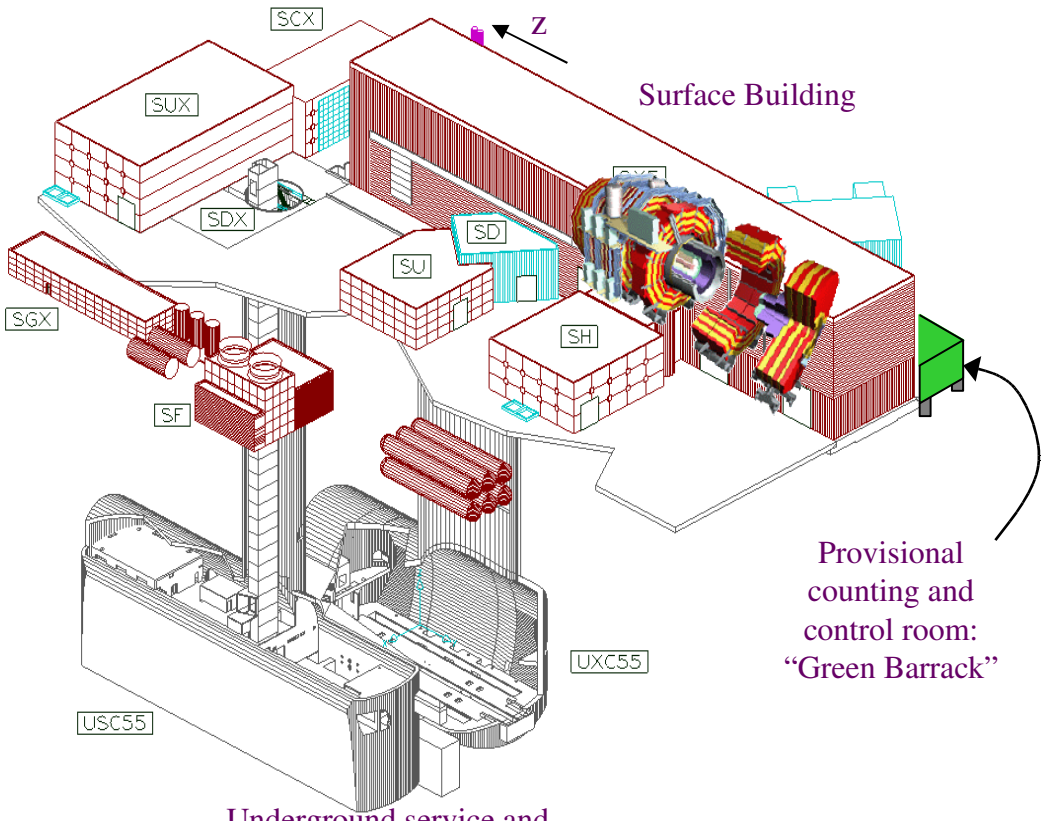
CMS commissioning constrains

CMS experimental hall ready to accept detectors only late 2006

Assembly of detector to be done as much as possible on the surface hall

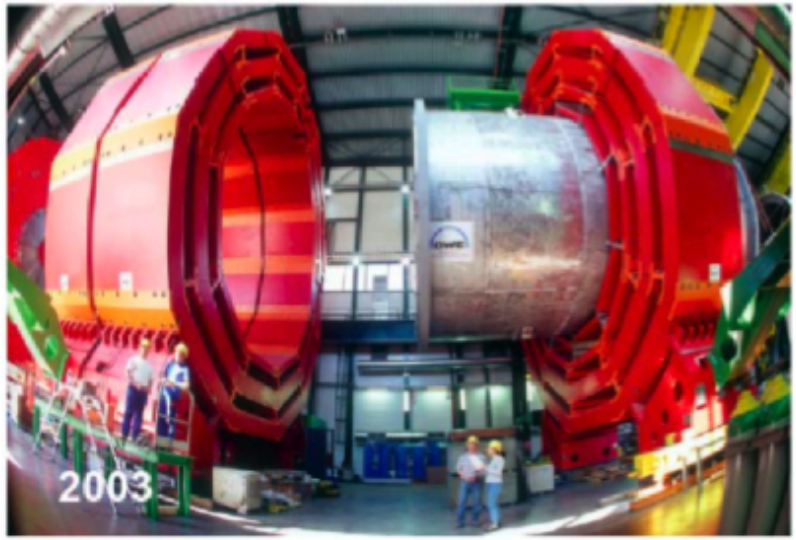
All subdetector pre-commissioned, calibrated in integration labs and/or test beam/cosmic stands

2001- 2006:
Surface: assemble the detector
Cavern: dig and prepare it

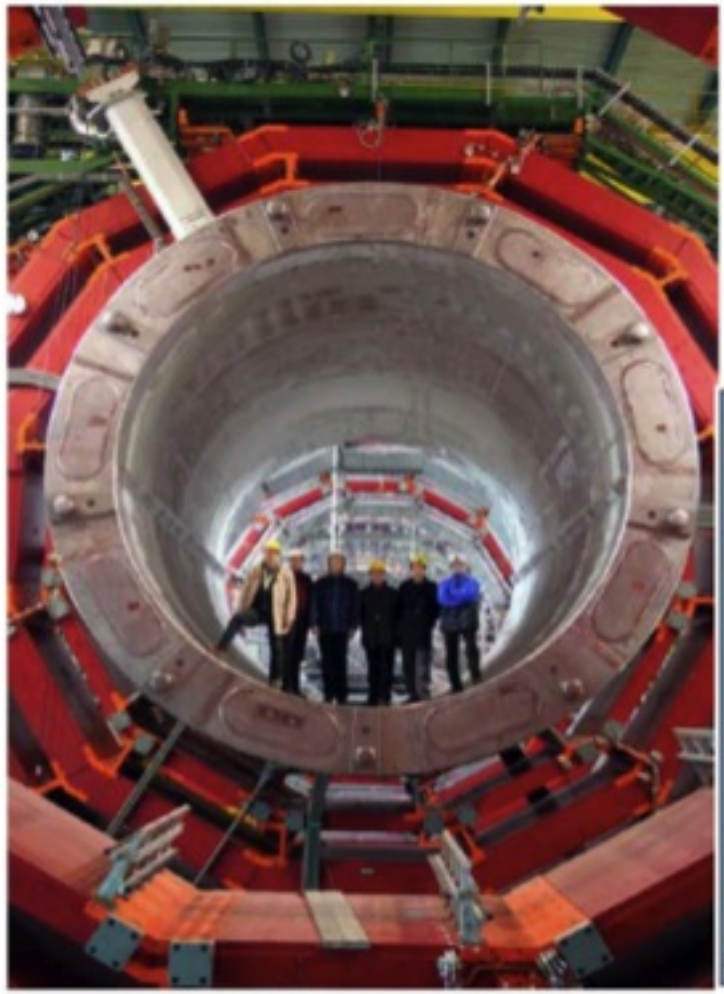


Surface and underground: 2001-2002

Surface and underground: 2003-2004



Surface and underground: 2004-2005



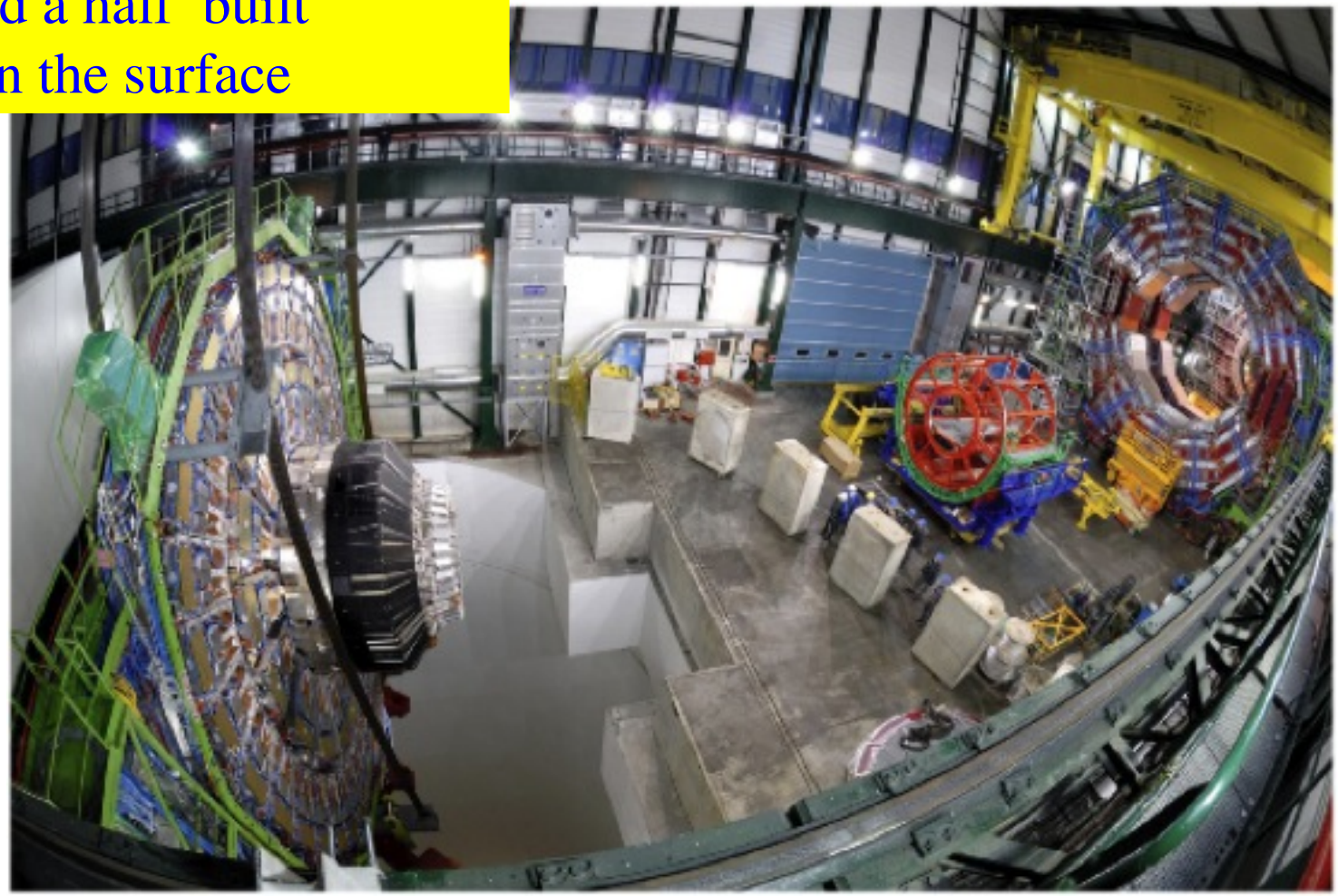
First elements of CMS were lowered
Into underground cavern in late 2006

Once upon a time there was an empty cavern

May 2006, not that long ago… we had no detector at all in the hall

Surface Hall and lowering shaft

But we had a half built detector on the surface

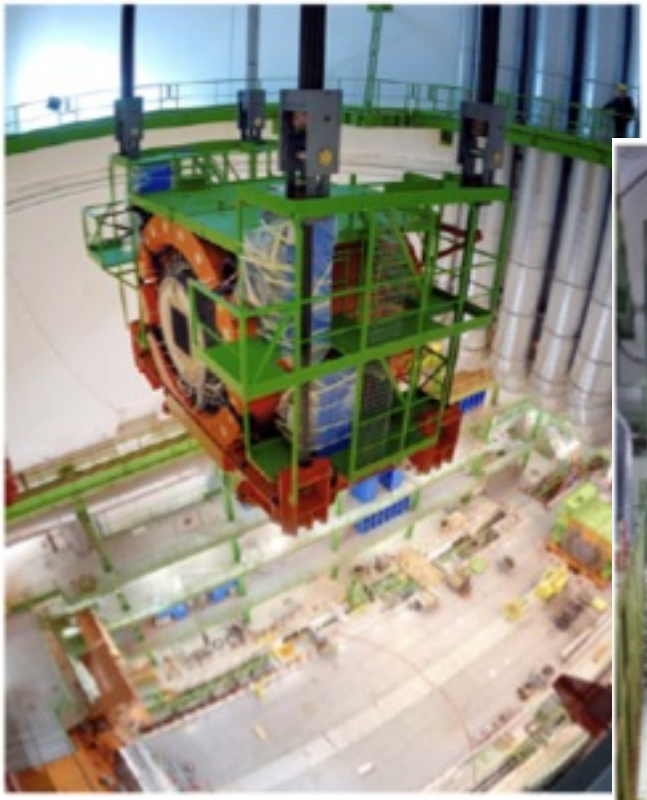


Let's fill the cavern

HF lowering Nov 2 , 2006

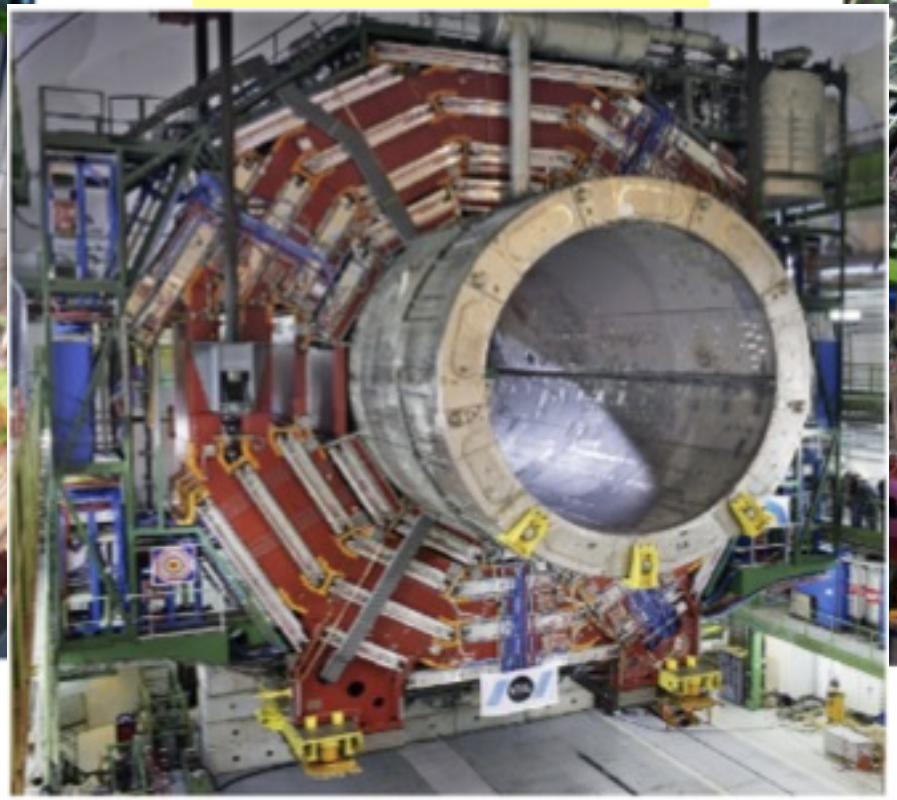
Heavy lowering

#1 Nov06: HF-



50,000 hours to recable YB0

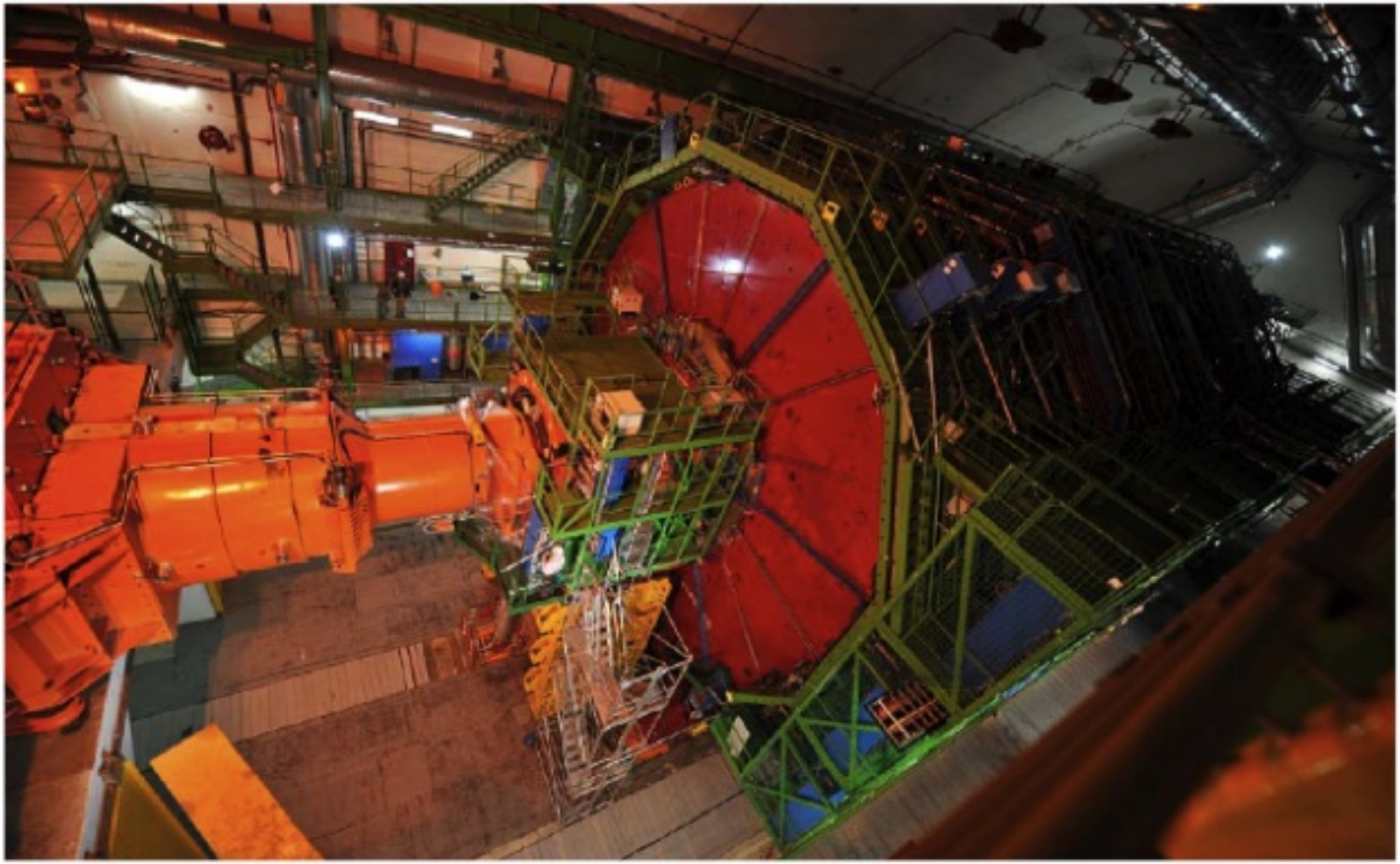
#9 Feb07 YB0



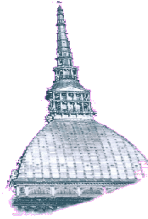
#15 Jan08: YE-1

Last element!

20:30 Sept 3rd, 2008: Final closure



CMS commissioning overview



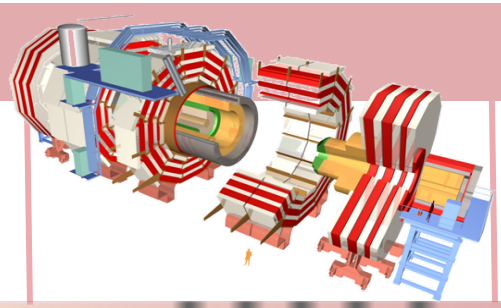
2006 | 2007 | 2008

computing commissioning

CSA06 | CSA07 | CSA08 CCRC08

surface commissioning

MTCC



heavy lowering

Tracker installed

Beam pipe bake-out

ECAL endc. installed
Pixel installed

CMS closed

CRAFT

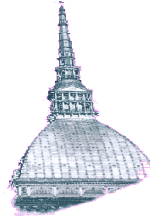
Global Runs | CRUZETs | Magnet tests 1st beams

underground commissioning

CMS dictionary:
CSA – **C**omputing, **S**oftware and **A**nalysis challenge
CCRC – **C**ommon **C**omputing **R**eadiness **C**hallenges
MTCC – **M**agnet **T**est and **C**osmic **C**hallenge
CRUZET – **C**osmic **RU**n at **Zero** **T**esla
CRAFT – **C**osmic **R**un **A**t **F**our **T**esla

I. Mikulec

Local and global runs



Global Run :

- Coherent exercise of CMS data taking in preparation for collisions
- 1 week of intense activity
- 6 GR in 2007, 8 in 2008
- Involves more and more subsystems
- ~ 100 ml cosmic triggers acquired

Local Runs :

- Use to debug the system, test configuration
- Single subdetector + additional Trigger chain

- Readout can be local VME with low rate) or global

Beam Run :

- September 10th – 19th LHC had beam!
- Sub-system time for development restricted

Commissioning strategies

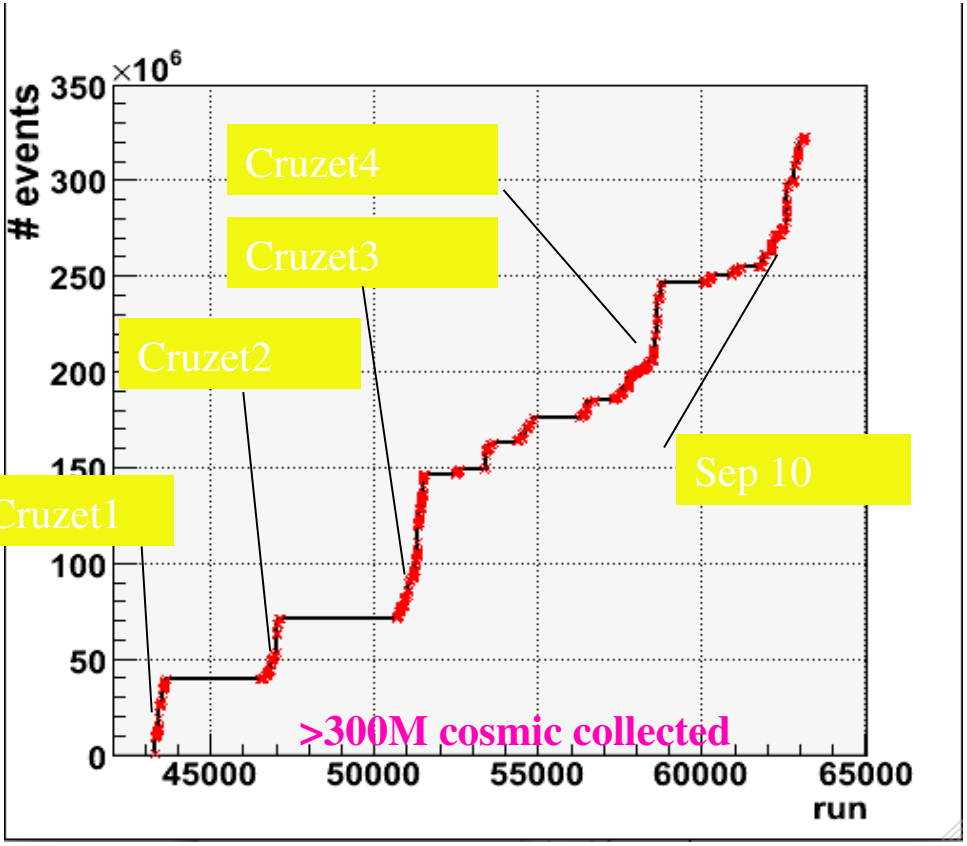
ntegrate parts of CMS into DAQ process as soon as they become available

est the trigger (L1, HLT) and L1 trigger throttling using cosmic and high rate random triggers

ntroduce 24/7 shift operation and test/develop DQM (Data Quality Monitoring)

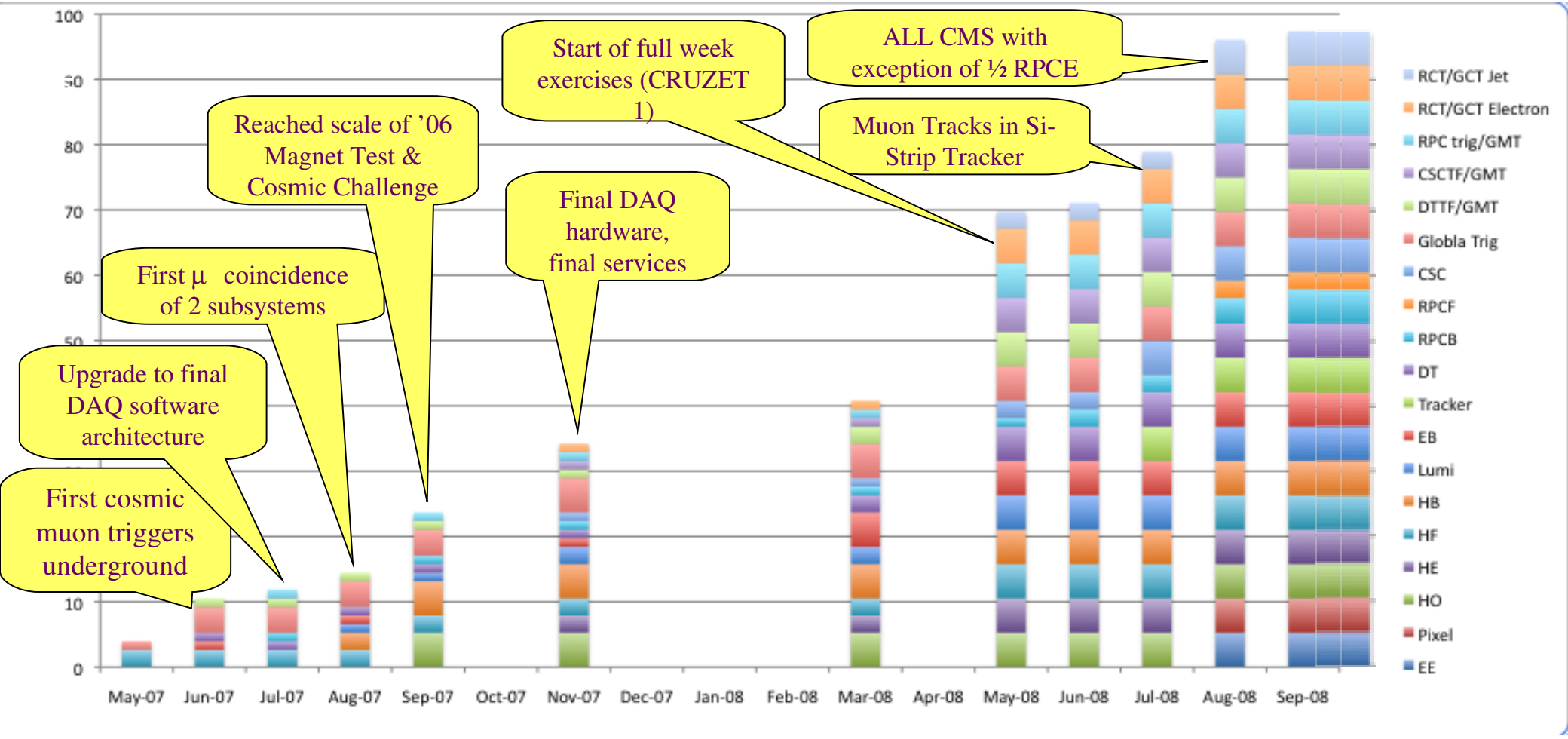
xercise data transfer offsite, CAF (CMS Analysis Facility) and Tier 0,1,2, prompt reconstruction, alignment and calibration

se collected data to understand trigger and read out synchronization and detector performance using inter-system correlations



Global Runs: who joined when

Sub-detector and trigger considered separately - 19 items, each equally weighted
(box size represents approx. fraction included (25%, 50%, 75%, 100%)



The “beam period”

-Pre-10.09.2008 beam tests : code name ‘synchronization tests’, ‘beam shots events’

-Beam started on September 10th

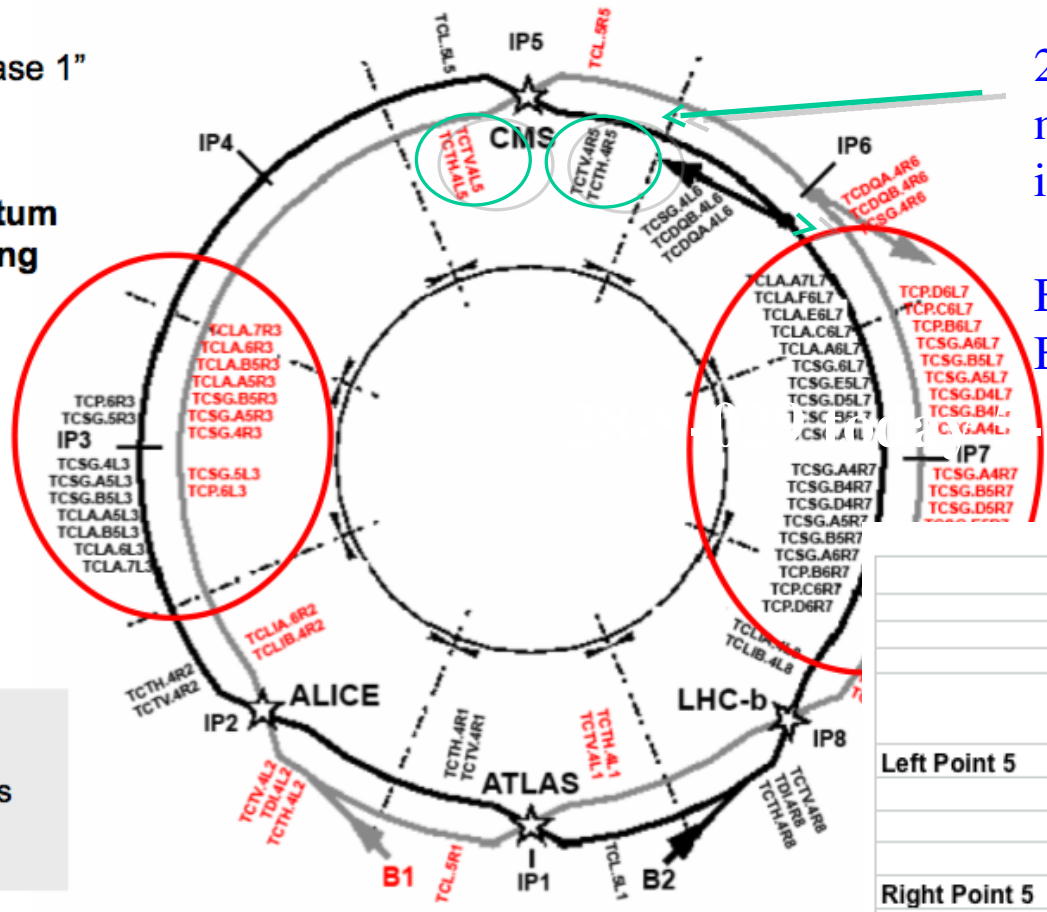
-Night, Sept 11th:Beam 2 captured by RF system

-Late evening of Friday Sept. 12th an old LEP HV transformer in point 8 failed, CMS put in a spare.

-Cryogenic back in service on the 19th morning

-September 19th 11:18 : what can you do with 200 MJ….

Global Run: Beam Shots - I



2 sets of collimators are placed at +- 146 meters away from P5 on the path of the incoming beam.

Beam 1 was stopped left of CMS
Beam 2 was stopped right of CMS

LHC collimators installation Schedule around Point 5

	Vacuum sub-sectors	START FROM IP [m]	TYPE	FUNCTIONAL POSITION NAME	Collimation phase
Left Point 5	A5L5	-185.097	TCL	TCL.5L5.B2	1
	B4L5	-150.47	TCLP	TCLP.4L5.B2	3
		-148.26	TCTH	TCTH.4L5.B1	1
		-146.58	TCTVA	TCTVA.4L5.B1	1
Right Point 5	B4R5	145.1	TCTVA	TCTVA.4R5.B2	1
		146.78	TCTH	TCTH.4R5.B2	1
		148.99	TCLP	TCLP.4R5.B1	3
	A5R5	183.524	TCL	TCL.5R5.B1	1

Global Run: Beam Shots - II

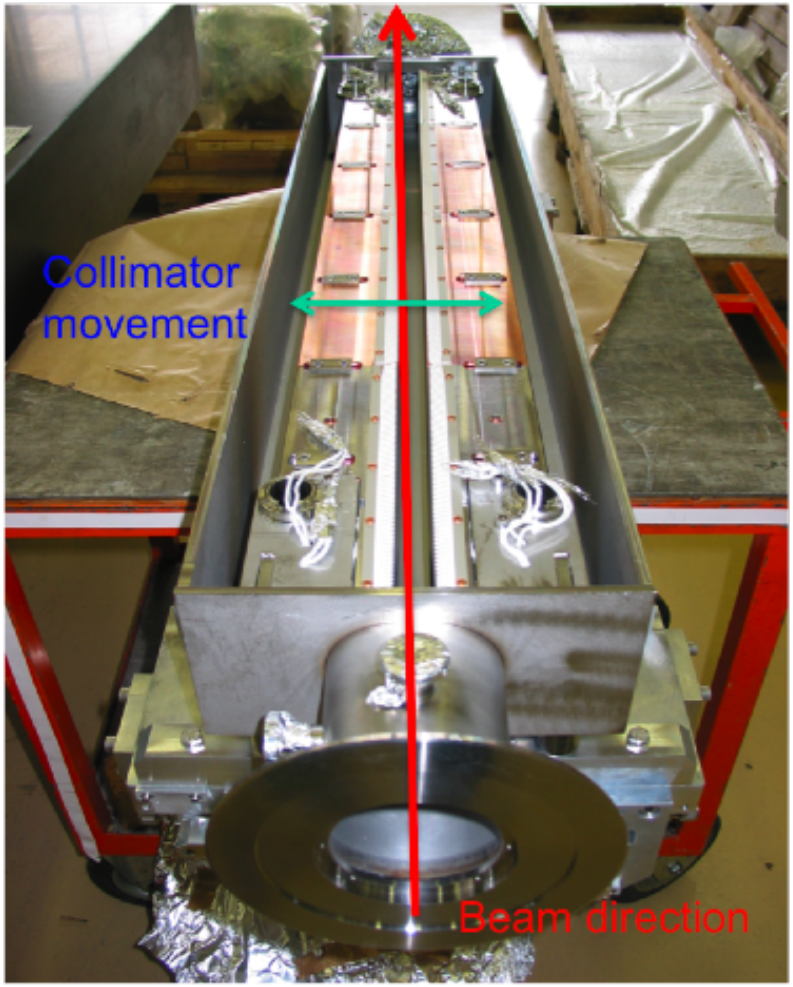
Each collimator is made of two blocks of tungsten, 1.2 meter long and ~ 10 cm wide .

Tungsten interaction length λ = 9.6 cm

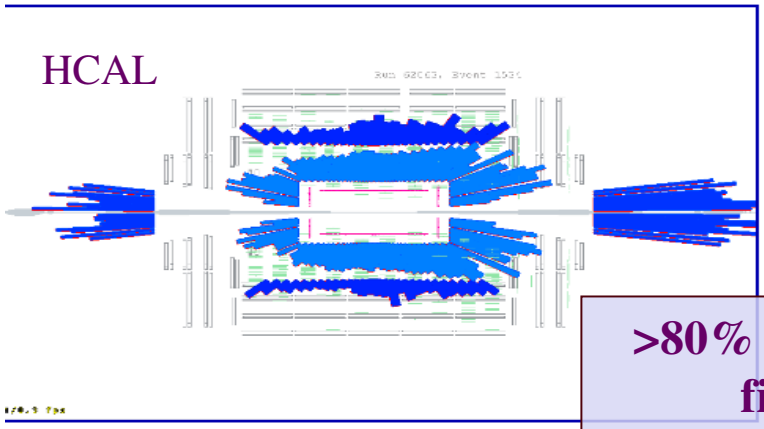
Laterally the shower is not contained, 2-5% leaks out. A lot of energy was released towards CMS:

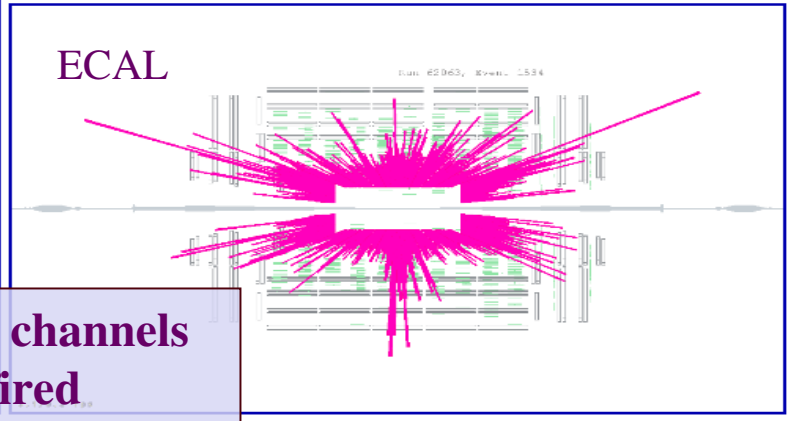
1% * 10^9 protons*450 GeV = 4.5 10^3 TeV

Indeed we saw a very large signal

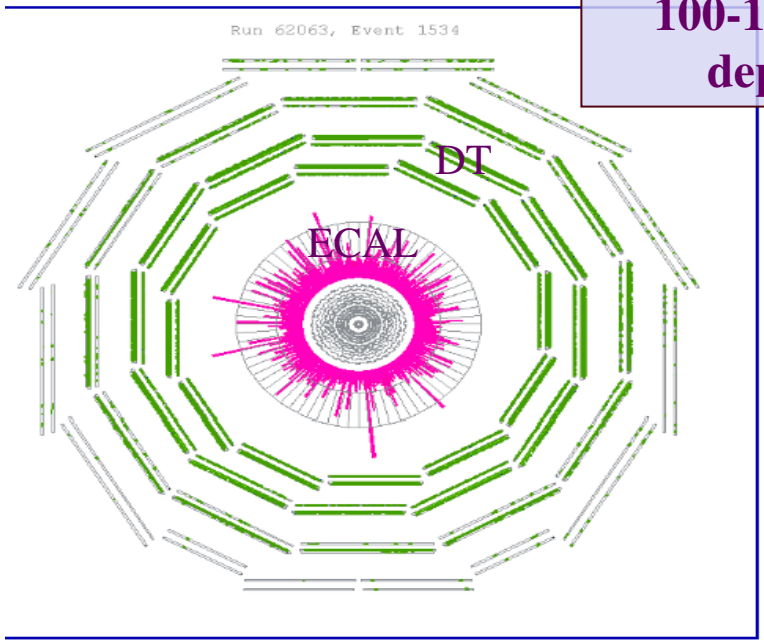


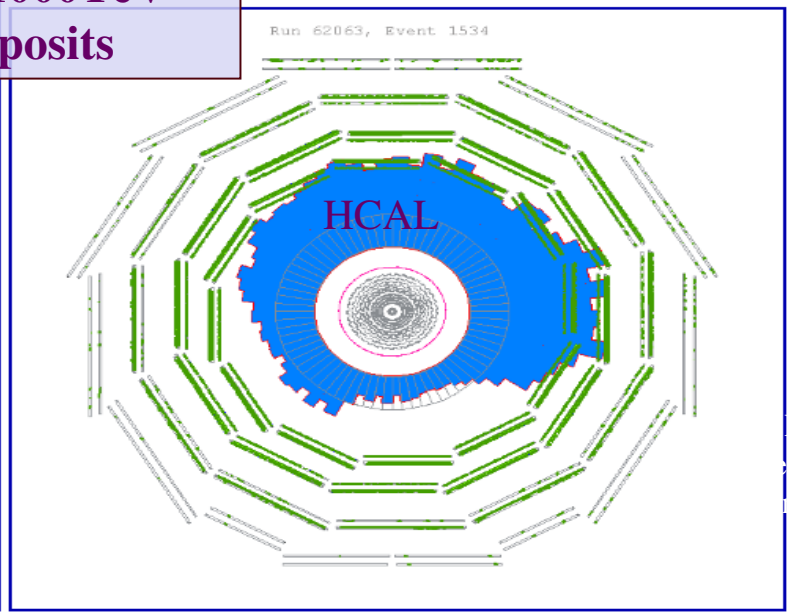
Global Run: Beam Shots - III





>80% channels fired 100-1000TeV deposits

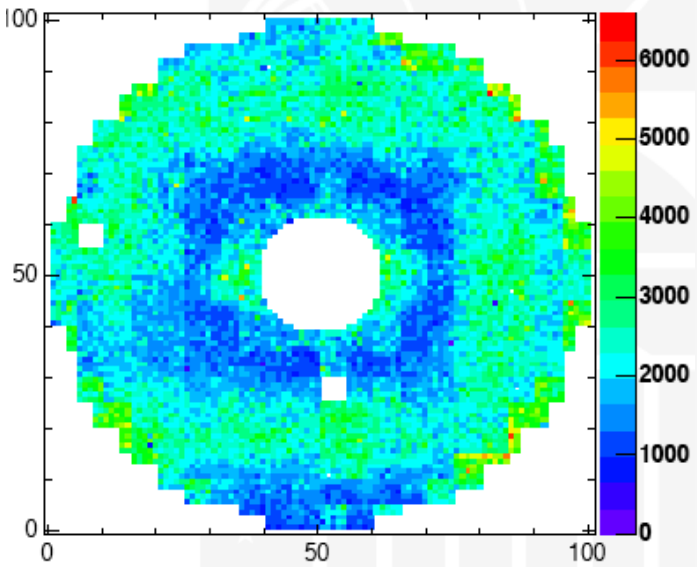




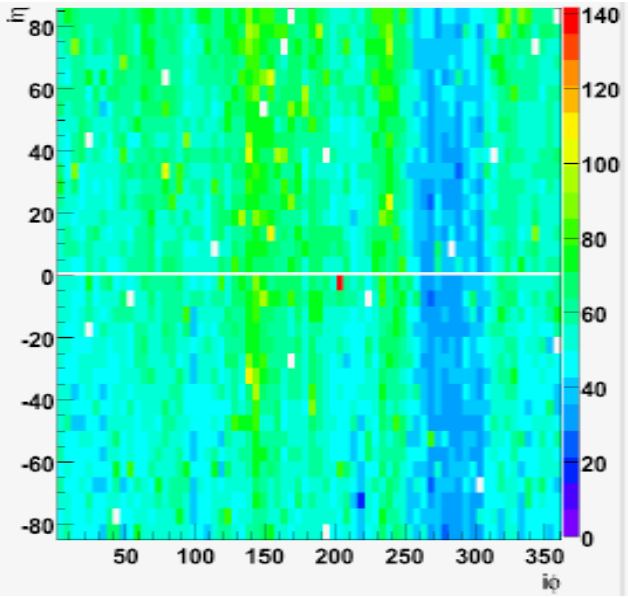
Beam triggers (BPTX, BSC) correctly timed in to CSC and HF triggers

Global Run: Beam Shots - IV

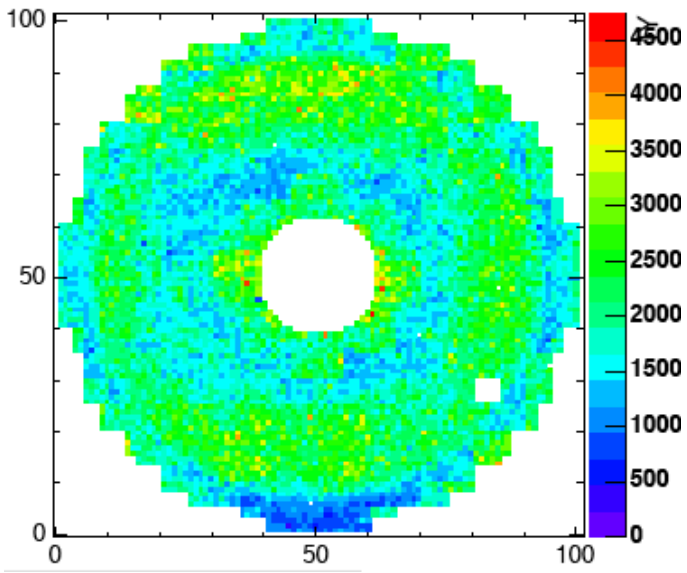
Endcap- ECAL



Barrel ECAL



Endcap+ ECAL

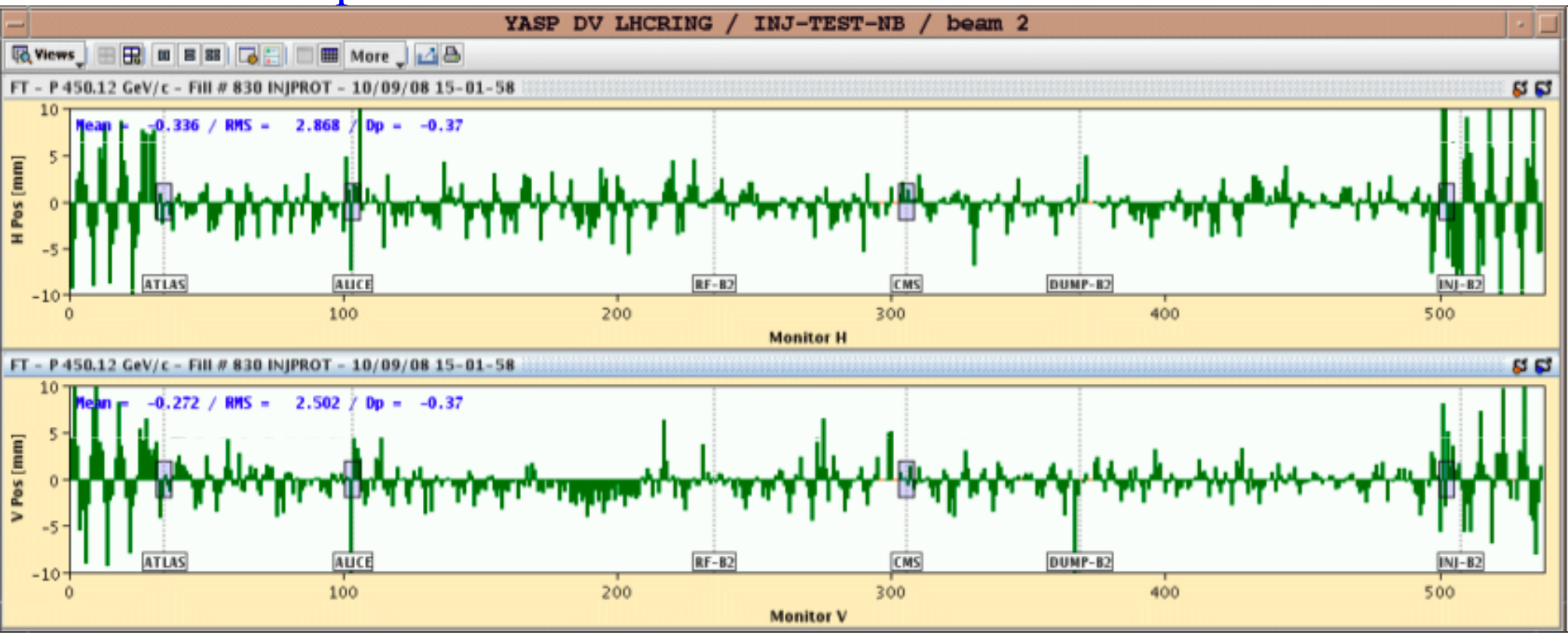


Splash events are a perfect tool to study occupancy, synchronization and bad channels

All ECAL crystals received a hit

How do you know the beam goes around?

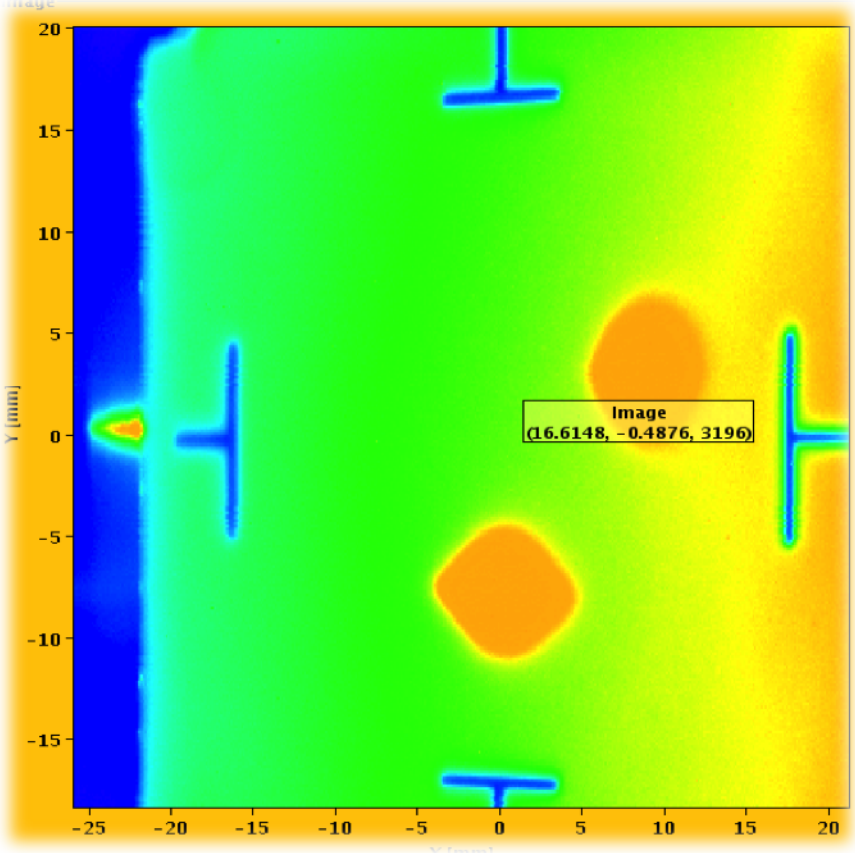
Beam position monitors!



Vertical displacement vs Position along the ring

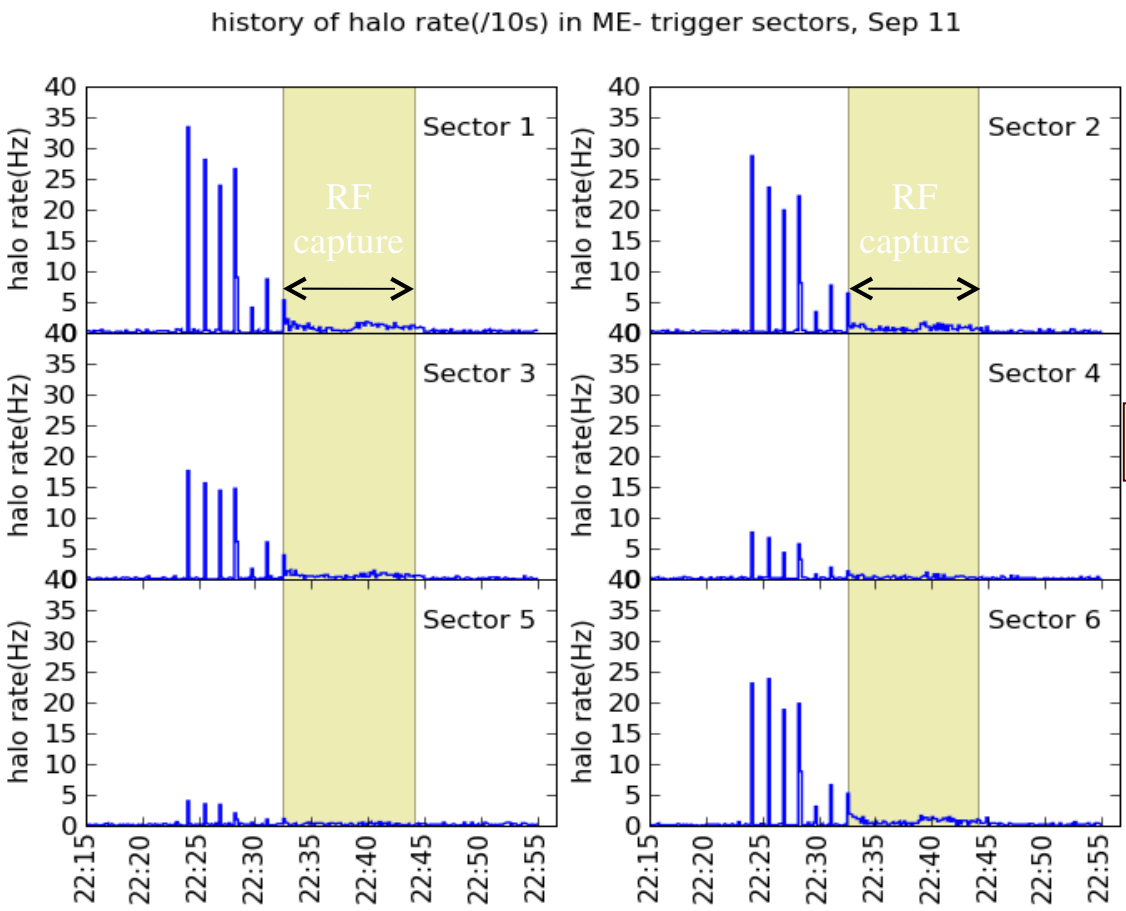
First Beam Around

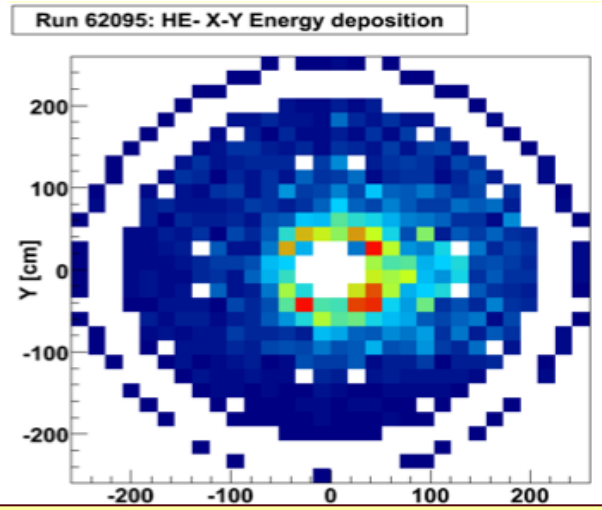
Sept 10th 10:30: two beam spots on a screen near ALICE indicate that the beam has made 1 turn.



Sept 11th: RF captured beam

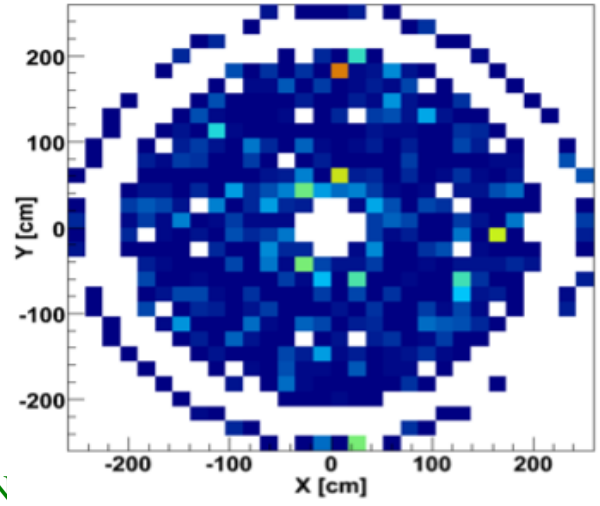
CSC halo trigger rates vs. time





Uncaptured

HCAL endcap energy deposits

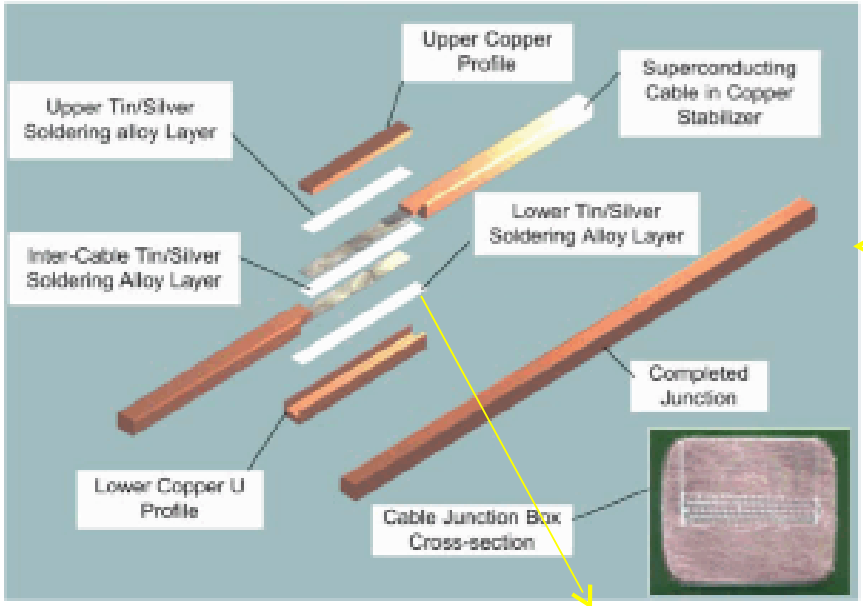


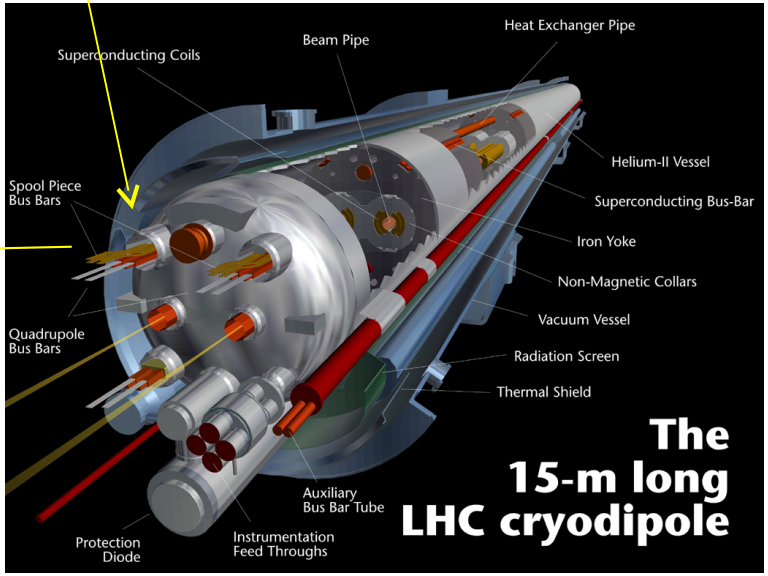
Captured

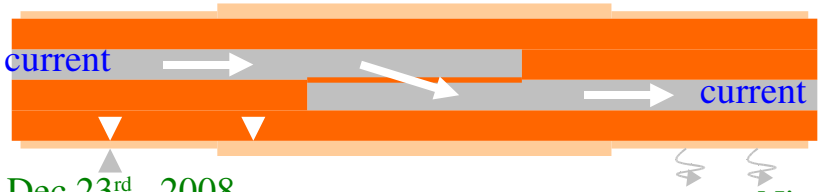
And then came September 19th 11:18…

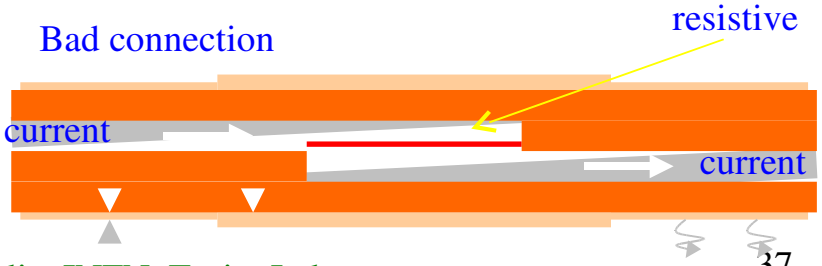
During the last commissioning step of main dipole circuit in sector 34, to 9.3kA ,
At 8.7kA, development of resistive zone in the dipole bus bar between Q24.R3
and the neighboring dipole.

Jörg Wenninger

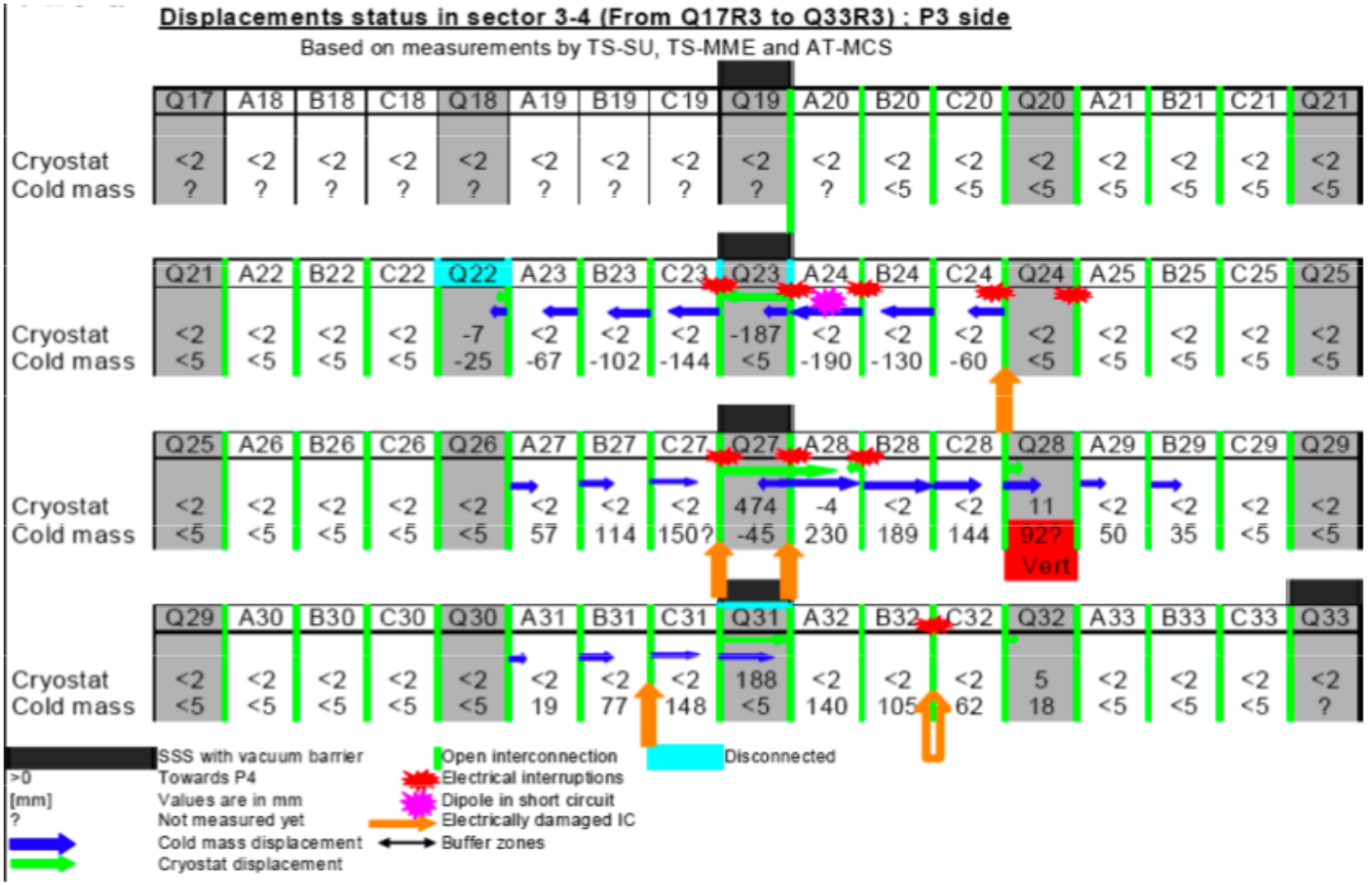




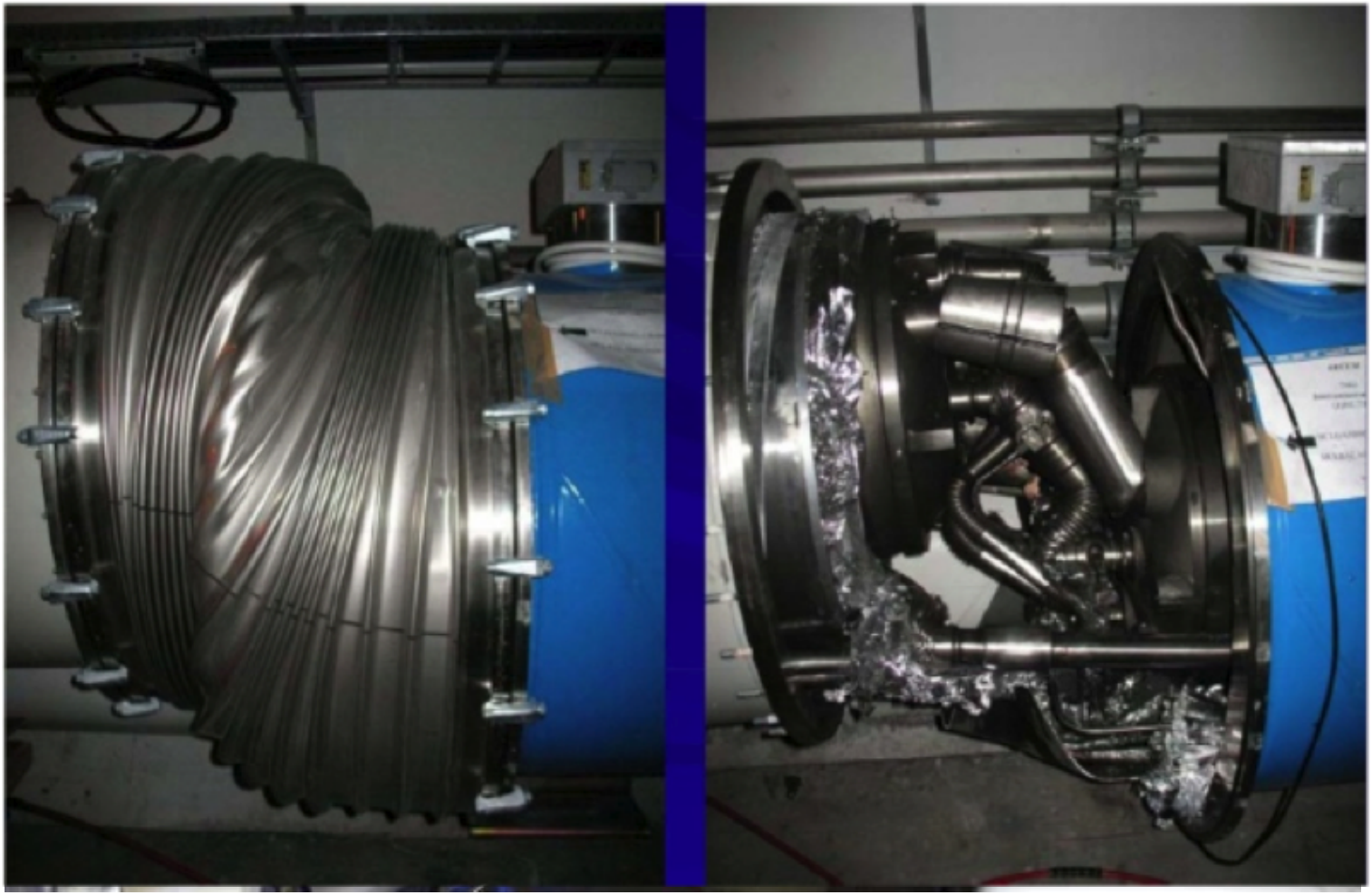




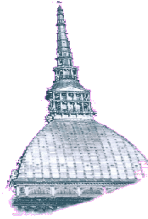
Displacements



LHC damage: before and after



Beam period: Summary



Jörg Wenninger

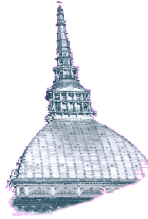
Start-up with beam:

- Despite totally crazy conditions the beam start-up was excellent.
- The speed of progress with beam2 exceeded even our optimistic hopes.
- A lot was learned, but not enough to be sure that the rest of the early commissioning will proceed as well as the first 3 days…

Sector 34 incident:

- Revealed a weakness in the installation quality assurance.
- Revealed a weakness in the magnet protection system which did not cover dramatic bus-bar/interconnect incidents.
- Inspection and repair of ~ 50 magnets will take most of the shutdown.
- Improvements in the quench protection system, ready summer 2009, should provide early warning/protection against similar events.
- The final improvement of the pressure relief system requires a warm-up of all sectors

CMS: Commissioning of the Solenoid



Before LHC start-up solenoid was raised to 3T in final configuration. Coil behaves quite well.

- Observed mechanical movement of CASTOR calorimeter in close proximity of beam-pipe.
- Gained access into CMS cavern on Monday 6 Oct. Beam-pipe was brought up to atmospheric pressure with Ne gas. CASTOR was then removed.

With much care the magnet was successfully ramped up to operational field (3.8T) on Friday afternoon 10 Oct.

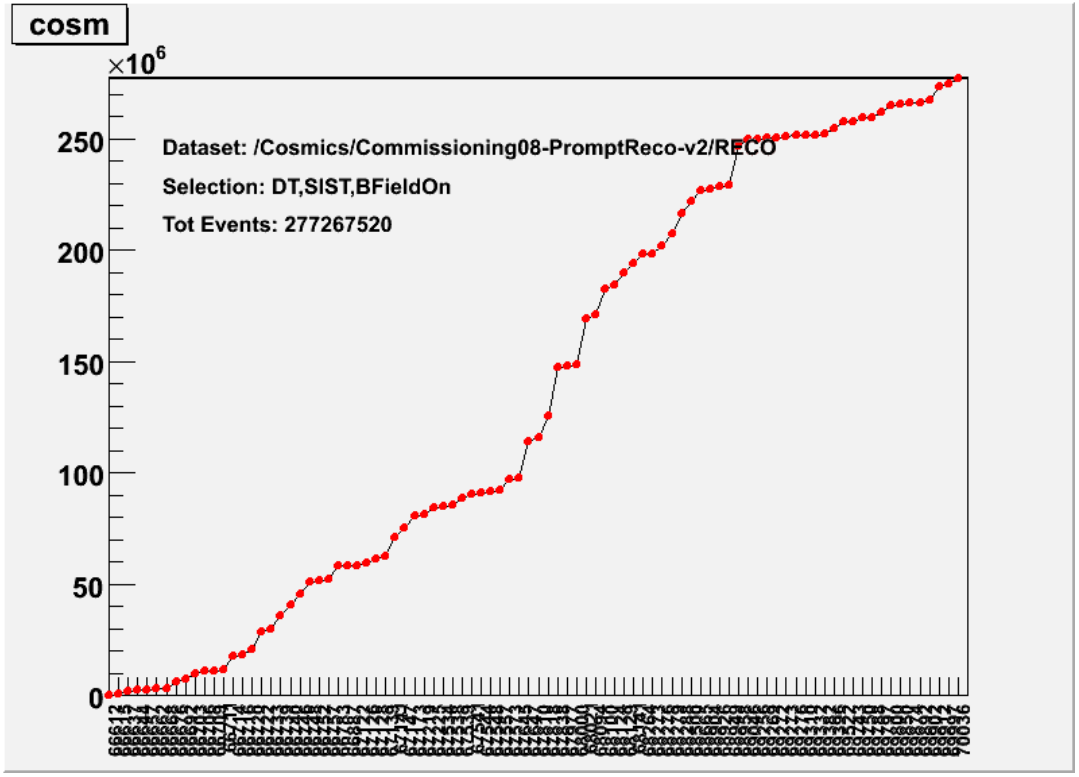
- It has been running at operational field for 4 weeks without problems.
- Many fringe-field measurements have been made, including in the triplet area.
- Raised to 4T to re-confirm margin. Measured with final shielding structures.
- Carried out a fast dump.

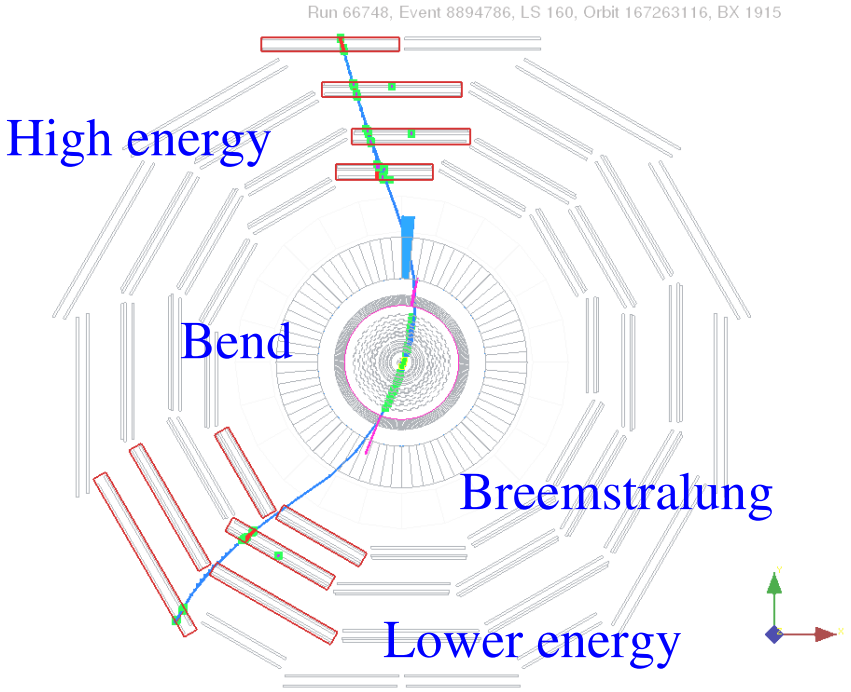
B field effects

- Bend particles
- Prevent the elevator from running
- Make your safety shoes stick to the metal floor
- Breaks laser lamps
- Makes the overhead lamp in cavern very noisy
- Stop the crane in the cavern

Global Runs At Four Tesla (CRAFT)
17 October-9 November @3.8T

CMS ran for 4 continuous weeks 24/7 and collected nearly 300M cosmic events with B=3.8T





Global run results

CRAFT goals as stated in CMS week have been met

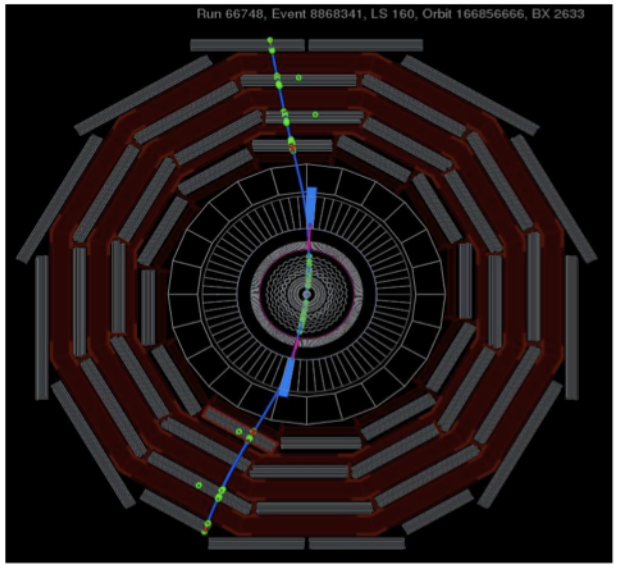
- ~ 300 M cosmic with B=3.8 Tesla and Pixel/tracker in readout
- 4 weeks of operational experience with continuous running

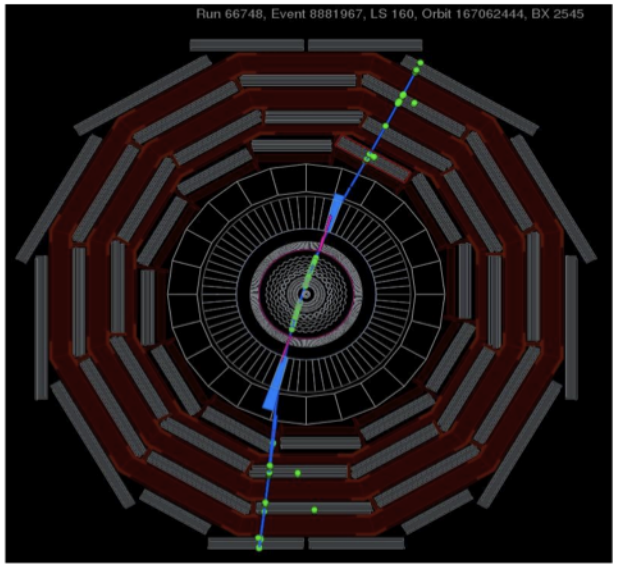
Achievements:

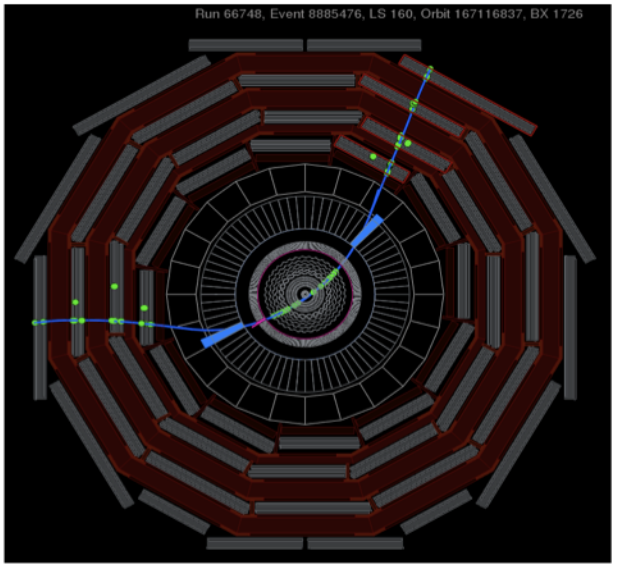
- We can run stably for the length of a LHC fill (record 24 hours long run)
- Calorimeter triggers reached 'maturity': basic trigger menus for LHC for both Electron and jet trigger have been deployed
- Ambient EM Noise sensitivity for RPC (affecting trigger): source identified
- Calibration sequences (ECAL transparency monitoring, DT pulsing, Tracker laser alignment) tested out/debugged
- Statistics achieved allowed tuning of fine synchronization of data pipelines (Pixel optimized in middle of CRAFT, Tracker internal synchronization)

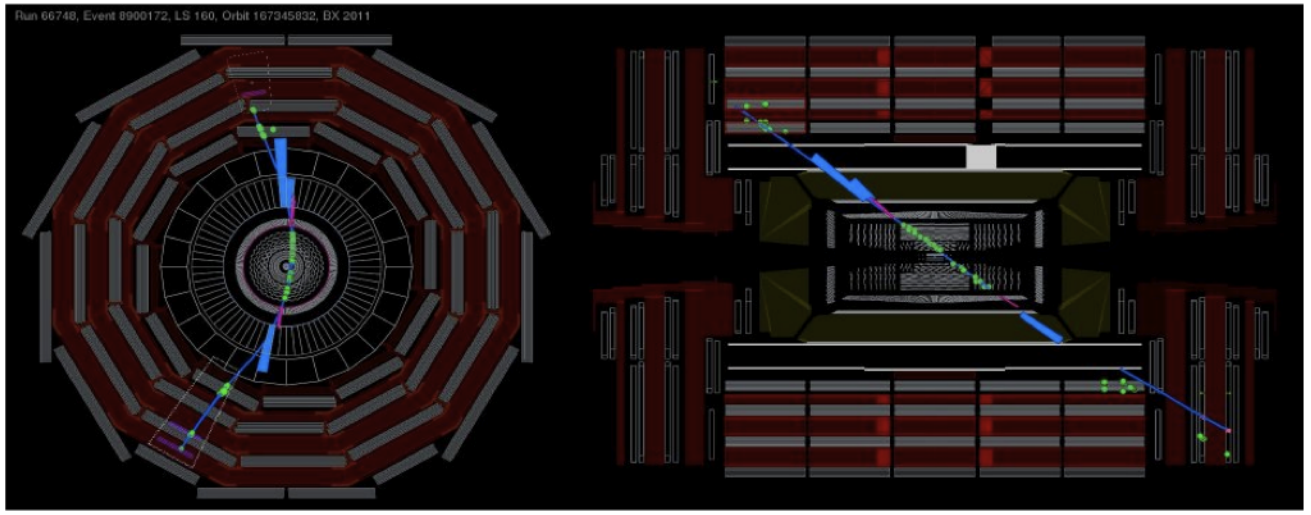
T. Camporesi

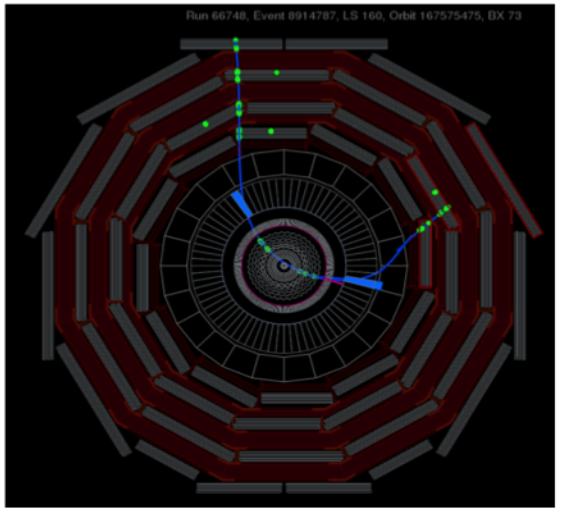
Global run: results



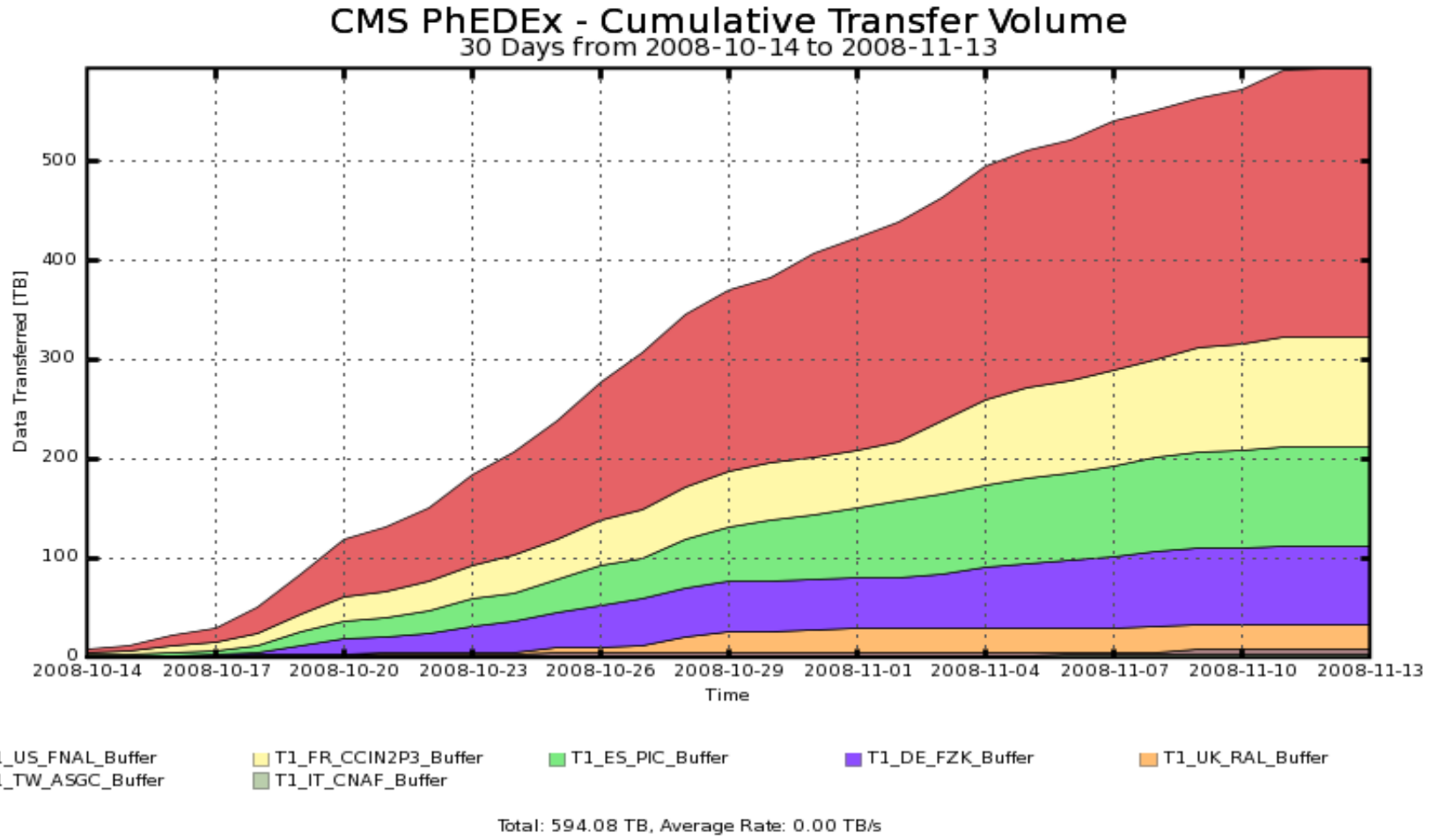






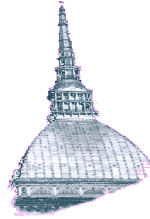


Data volume from CERN to…



600 TB of data was moved around

Global Run: Pixel and Tracker



Strip Tracker

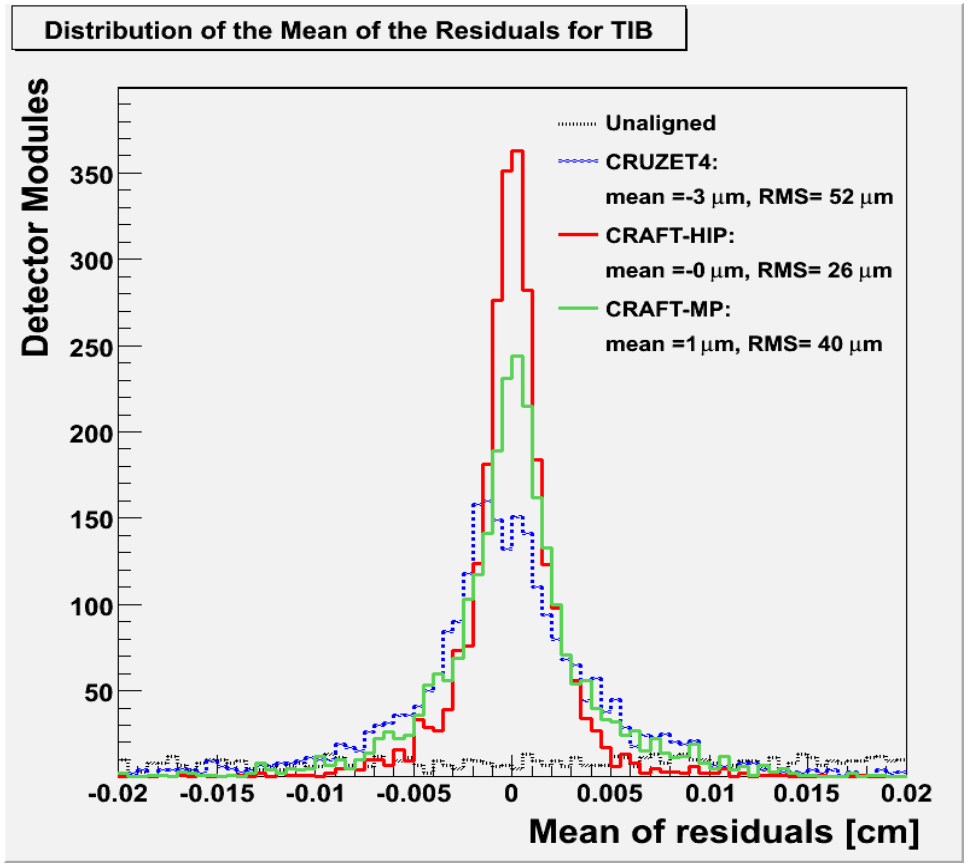
- TOB: 98.2% (0.6% recoverable)
- TIB/TID: 96.9 % (1% recoverable)
- TEC+: 99.2%
- TEC-: 97.8 % (1.7% recoverable)

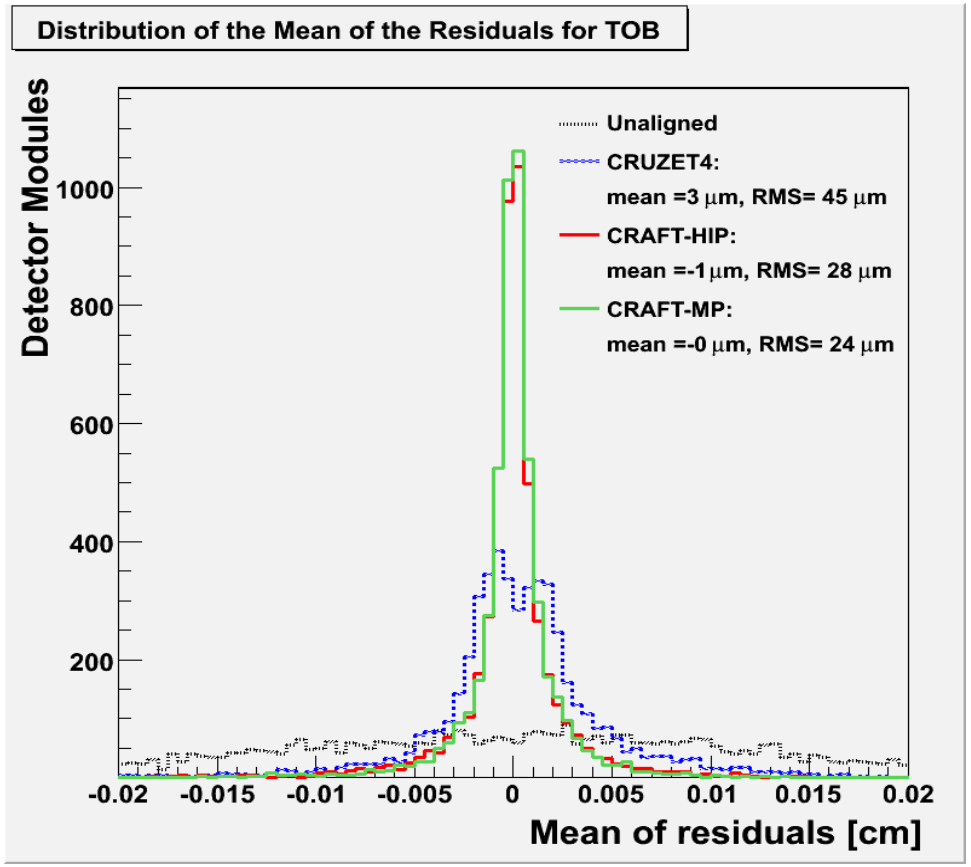
Pixels

- Barrel pixels: 99.1%
- Forward pixels: 94.0%
  - Dominated by some readout chips without bias voltage and others without low voltage
  - Reparation will be attempted during shutdown

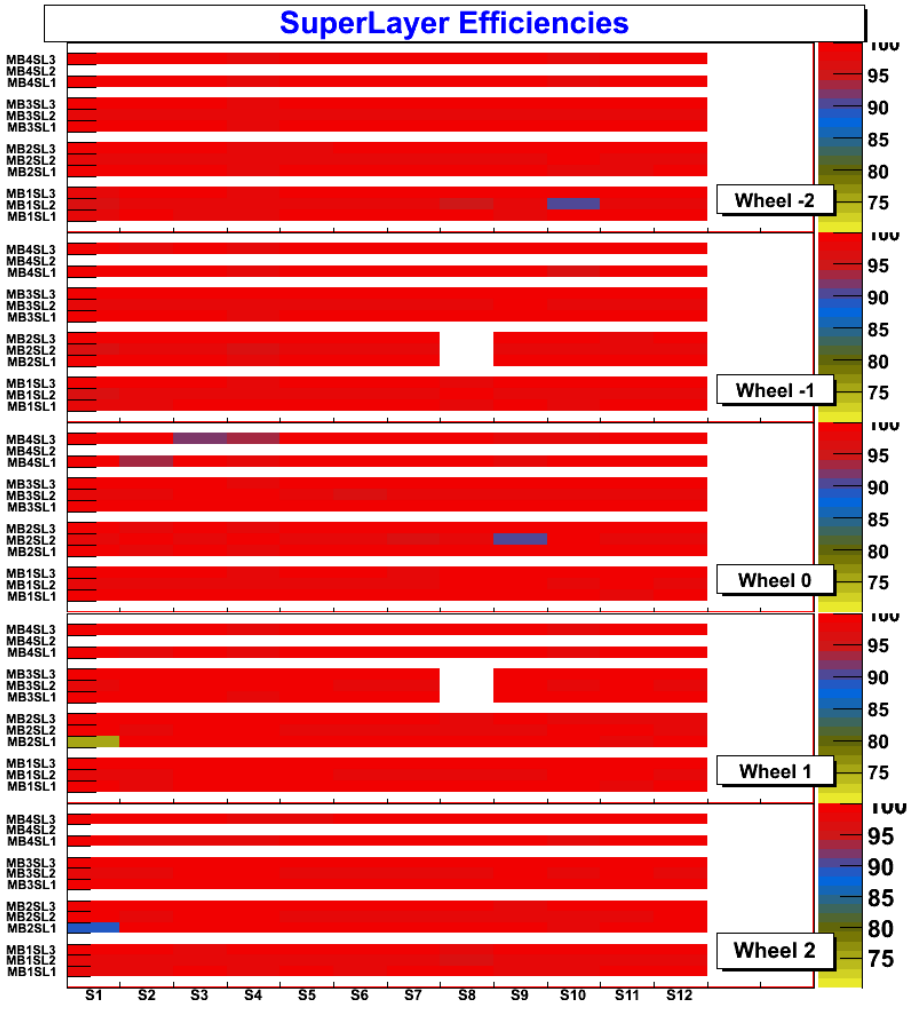
Tracker Barrel Alignment

Inner Barrel RMS = 26μ m Outer Barrel RMS = 28μ m



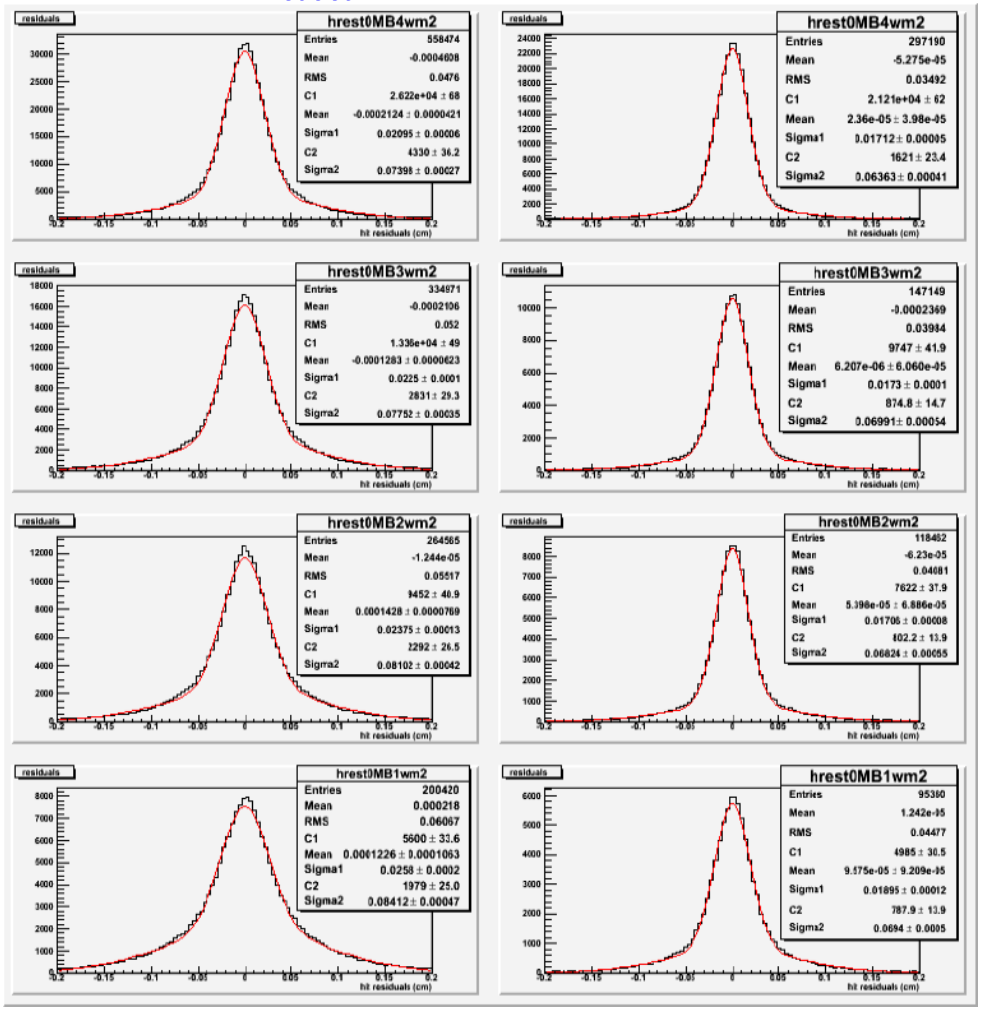


Drift Tube efficiency and resolution

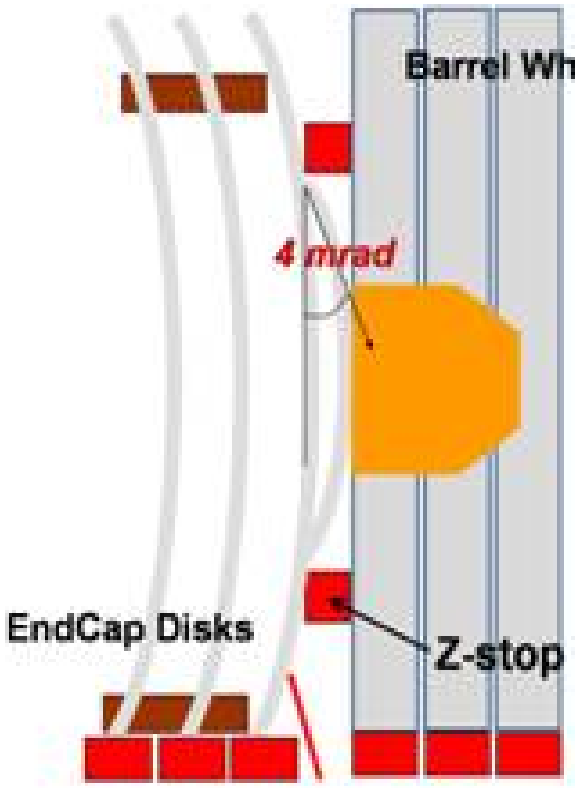


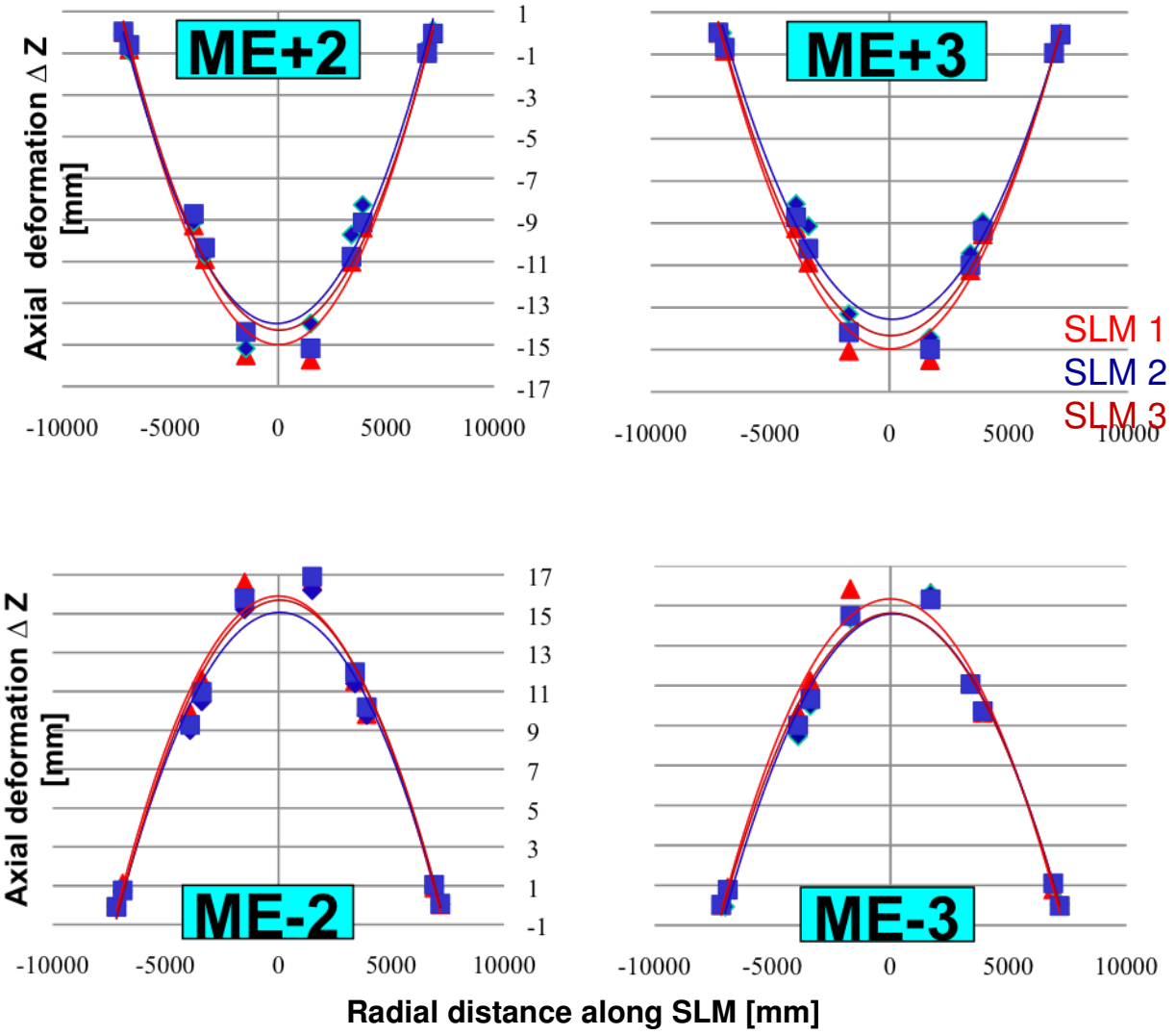
Data

MC



Measured End-cap Deformation at 3.8T

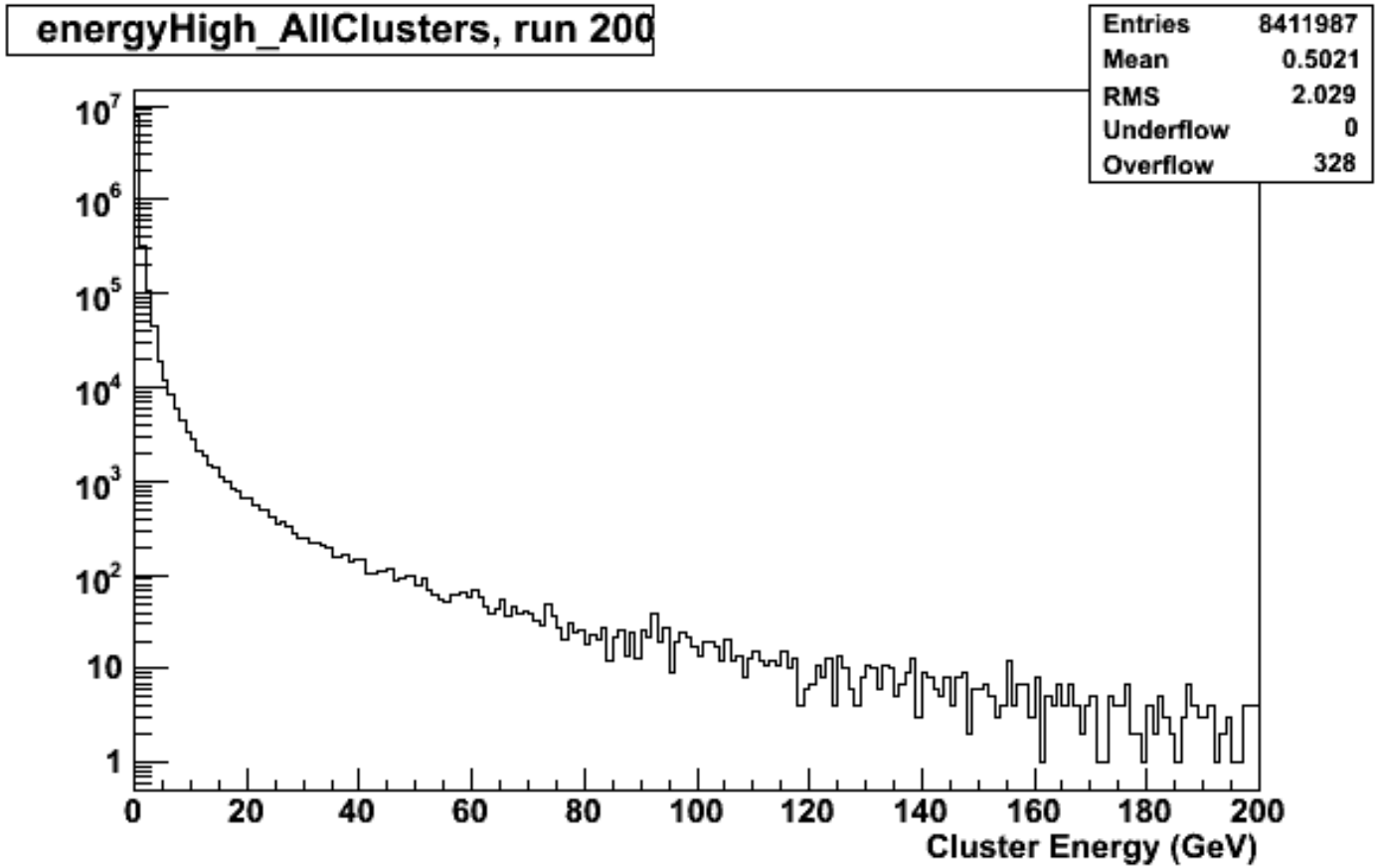




3 Straight Line Monitor (SLM) Laser Lines per Muon Endcap Station

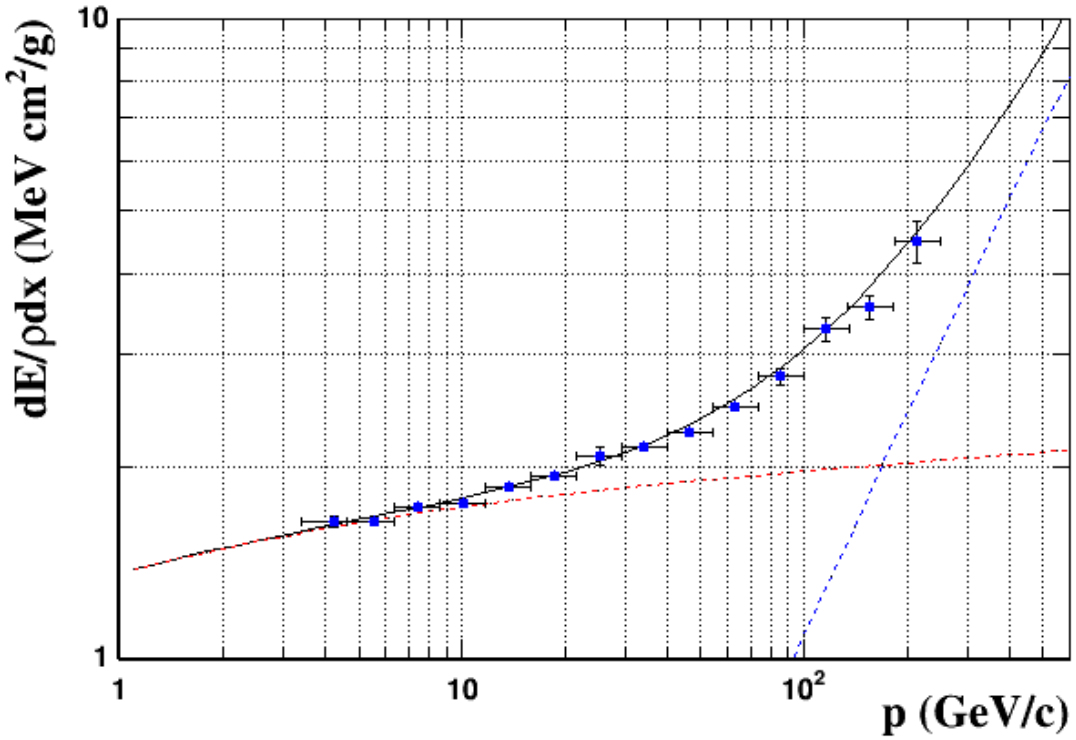
Energy in the electromagnetic calorimeter

How much energy a cosmic muon can deposit? A lot!!

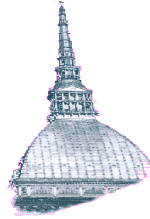


Stopping power in PbWO4

Cosmic muons release energy due to collision loss (red) and bremsstrahlung radiation (blue). Results indicate the correctness of the tracker momentum scale and of the energy scale in ECAL calibrated with electron at test beams.



CMS highest priorities during shutdown



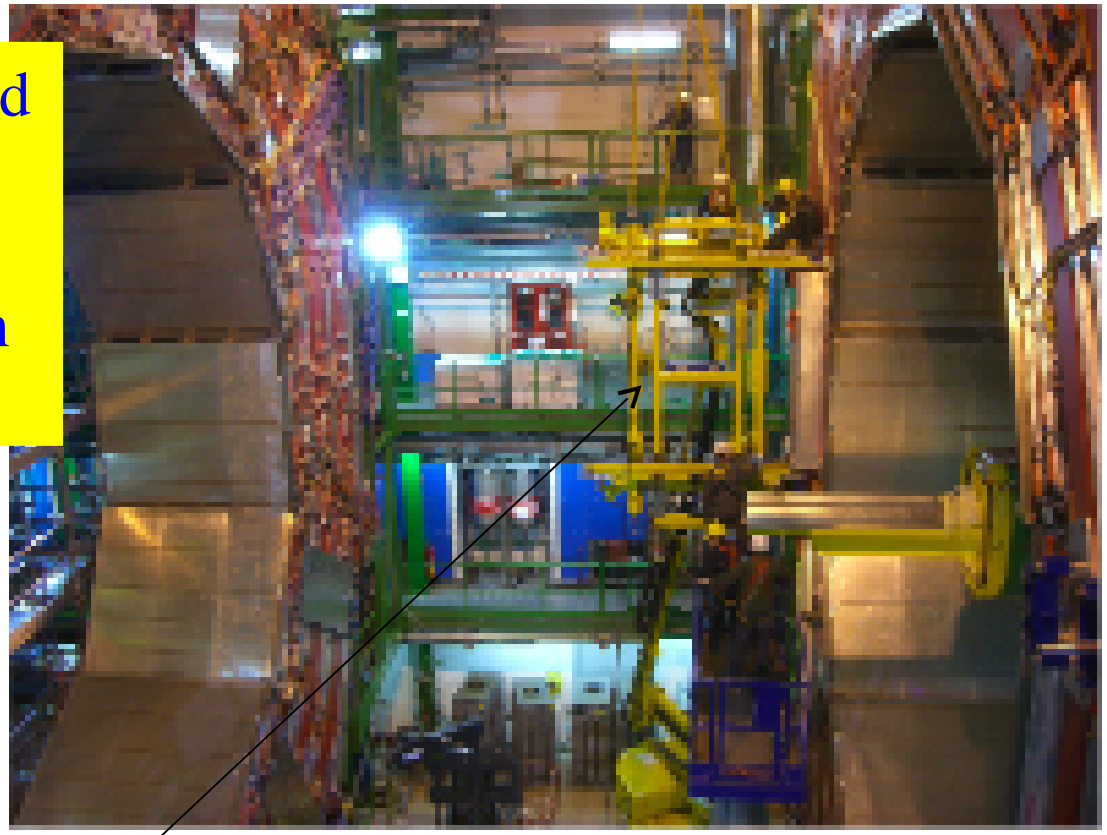
Highest priorities (everything necessary for safety and ALARA)

- Repair or re-work, in areas which will acquire significant activation (ALARA):
  - Preshower (last piece missing)
  - TOTEM T1 and T2

- Modifications to closing system of wheels, disks and shielding
- Modification to access platforms - reduce risks to detector and beampipe
- Infrastructure (cooling, elect. supply) diagnosis, repair and improvement
- Repairs necessary to achieve required 2009 performance (integrated lumi≅ 100pb^{-1}?)
- Set-up of full radiological screening and material tagging/classification/tracing for 2009 run.

Note: CMS can be re-opened in a few days

This is CMS opened in the experimental hall: it's actually possible to work on it



Muon chambers repair

LHC planning

- Restart in (late) summer of 2009 with beam.
- Beam intensity and energy limited to minimize any risk.

A. Upgrade of the quench protection system for precision measurements and protection of all interconnects :

B. Modifications of commission procedure to include cryogenic/calorimetric information and systematic electrical measurements

Final decision taken in conjunction with the experiments, possibly by February

Conclusion and outlook

CMS is a working experiment, we would have been ready for beam

A very personal timeline: